Optimization of Removal of Iron and Manganese from Groundwater using the samples from Chicha Plant, Kelantan

by

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Certification of Originality

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgments, and that the original work contained herein have not been undertaken or done by unspecified sources or persons

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Abstract

Groundwater is presently one of the major sources of water supply in Kelantan. The problems with iron in water are mainly aesthetic. Iron gives water a sour, metal taste, stains laundry, and food cooked in the water receives an unappetizing colour.

This research is focused on removal of iron and manganese from groundwater. The area of focus was mainly the Chicha Kelantan Groundwater plant. The removal of ferrous iron (Fe (II)) and Mn in groundwater has been generally achieved by simple aeration, or the addition of an oxidizing agent or the lime treatment. Aeration has been shown to be very efficient in insolubilization of ferrous iron at a pH level greater than 6.5 and maintaining iron concentration 0.3 mg/l. Also it is effective for maintaining concentration of 0.05 mg/l for manganese.

In this study, some of the removal methods were experimented in the Chicha and in UTP such as aeration and coagulation with all complete results attached. It can be concluded that coagulation, flocculation after aeration further decrease the Fe and Mn concentrations in the water. Concentrations of Fe are low as 0.02 mg/l and for Mn are 0.035 mg/l which is a tremendous result. Although lime is not recommended, sodium hypochlorite might be an ideal replacement for other chemical additions. After hypo addition, concentrations of Fe are 7.95 mg/l and Mn is 13.2 mg/l considering very high dosage of Fe & Mn solution. It is effective to reduce both Fe & Mn concentrations.

Acknowledgment

First and foremost, I would like to thank my supervisor, Dr. Shamsul Rahman Mohamed Kutty. Without his guidance, feedback and encouragement, this project would not have been possible. It has been valuable experience to work with Dr. Shamsul.

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Chapter 1

1.0 INTRODUCTION

1.1 Background of Study

Iron is the fourth most abundant element by weight in the earth's crust. The presence of iron in natural waters, with or without attendant organic pollutants, causing water treatment problems is well known, and its removal is essential in order to make water esthetically acceptable, as well as portable. Because of the various problems that may be caused when iron appears in community water supplies, the World Health Organization specifies an upper limit of 0.3 mg/L for iron in drinking waters. Iron occurs in two oxidation states—the divalent ferrous form, Fe(II), and the trivalent ferric form, Fe(III). In an aqueous environment, both soluble and insoluble species of hydrolyzed iron may be co-present. The hydrolysis products of ferric iron have very low solubility at the pH of natural waters. Under oxidizing conditions most of the iron in natural waters is precipitated as ferric hydroxide. Oxidation of iron (II) can be achieved by the addition of chemical oxidants, or by aeration. Aeration has been shown to be very successful in oxidizing ferrous iron at a pH of greater than 6.5. However, the oxygenation of ferrous iron proceeds rather slowly at lower pH. Calcium carbonate, which is a main component of limestone, provides an alternative means of neutralizing acid water. Its main advantage over lime is its lower price, and the production of smaller sludge. As mentioned before, iron occurs in two main forms:

Dissolved iron: Dissolved or ferrous iron is usually found only in groundwater supplies that have not been exposed to oxygen. Water containing ferrous iron is clear and colorless. Upon contact with the air, oxygen is absorbed and reacts with the dissolved iron to form insoluble ferric oxide, also know as iron oxide or "red rust".

Undissolved iron: Insoluble ferric oxide is visible as a solid precipitate in water. It can color the water yellow to reddish-brown. It is usually formed from the oxidation of dissolved iron by exposure to oxygen or to other oxidants such as chlorine or ozone. If rust-colored stains are observed inside the components of an automated watering system on a chlorinated water supply, the stains are probably ferric oxide.

The iron and manganese that are dissolved in the water are said to be in solution or in a reduced form. In this form, they are often tied up with other dissolved salts such as bicarbonates, sulphates or hydroxides; or they maybe linked to certain organic materials. In their soluble or reduced state, iron and manganese are normally colorless and you cannot tell by the appearance of the water if they are present. However, once they become exposed to air or certain other chemicals, they change from a soluble to an insoluble form and yield the rusty colour or sediment which most people are familiar with.

1.2 Problem Statement

Ferrous-Iron oxide concentrations are very rich in groundwater. Concentrations more than 0.3 mg/l are considered troublesome and may cause severe health problems. Also Mn concentrations more than 0.05 mg/l are considered very dangerous to human health. Therefore, it is imperative to minimize the concentrations of ferric-iron oxides and manganese to standards set by WHO.

1.3 Objectives and Scope of Study

The main objective of this project is to remove iron oxide and manganese concentration from groundwater. Samples of groundwater were taken from Chicha Groundwater plant in Kelantan. Series of experiments were conducted such as aeration, jar test, ph treatment test at the plant to obtain more accurate, credible results. Two batches of results were obtained from the series of experiments including the Chicha's own experimental data and also another set from UTP lab experiments. The secondary objective of this project is to improve and evaluate the performance of Chicha Plant. Evaluation includes comparison of the results obtained from Chicha and tackling the current manganese problem present at the Chicha plant.

Chapter 2

2.0 LITERATURE REVIEW AND THEORY

2.1 Iron Removal Methods

The presence of iron is probably the most common water problem faced by consumers and water treatment professionals. The secondary (aesthetic) maximum contaminant levels for iron and manganese are 0.3 milligrams per liter (mg/l) and 0.05 mg/l, respectively. Iron and manganese in excess of the suggested maximum contaminant levels usually results in discolored water, laundry, and plumbing fixtures. Small amounts of iron are often found in water because of the large amount of iron present in the soil and because corrosive water will pick up iron from pipes. Clothing washed in water containing excessive iron may become stained a brownish color. The taste of beverages, such as tea and coffee, may also be affected by iron. Manganese produces a brownish color in laundered clothing, leaves black particles on fixtures and as with iron, affects the taste of beverages, including coffee and tea. Well water from the faucet or tap is usually clear and colorless. However, when water containing colorless, dissolved iron is allowed to stand in a cooking container or comes in contact with a sink or bathtub, the iron combines with oxygen from the air to form reddish-brown particles (commonly called rust). Manganese forms brownish-black particles. These impurities can give a metallic taste to water or to food. The rusty or brown stains on plumbing fixtures, fabrics, dishes, and utensils cannot be removed by soaps or detergents. Bleaches and alkaline builders (often sodium phosphate) can make the stains worse. Over time, iron deposits can build up in pressure tanks, water heaters, and pipelines, reducing the quantity and pressure of the water supply. Unluckily, iron and manganese can often be quite difficult to treat. This is due primarily to the fact that iron can be present in several forms, and each form can potentially require a different method of removal. Causes of poor performance of conventional iron removal processes are listed below followed by iron removal processes.

a. low oxidation pH

Usually pH would tend to decrease in oxidation stage. So usually addition of certain chemicals would optimize it. The importance of optimizing the pH is to get the suitable pH for the other processes. Since oxidation is one the first processes it is imperative that all parameters should be taken into consideration. (S. K. Sharma, 2001)

b. short time for oxidation

The single most important factor in the control of iron and manganese oxidation is that sufficient oxidation be conducted with sufficient detention time to allow for complete and efficient removal. In general, the designer has a vague understanding of the reaction chemistry of iron and manganese and, therefore, is subject to making errors with respect to judgment on the detention time required for the oxidative reaction of iron and manganese. (S. K. Sharma, 2001)

c. negative effect of chlorination

There are numerous negative of effects of chlorine which is used in chlorination process. Chlorine, as well as other disinfectants, reacts with certain water constituents to form new compounds with potentially harmful long-term health effects. Chlorine disinfection by-products have been extensively identified and assessed for toxicity. Considerably less is known about the nature and toxicity of the by- products of the other disinfectants, ozone, chlorine dioxide, or chloramine. The levels of potentially toxic chlorination by-products can be reduced through appropriate treatment while maintaining the microbiological quality of drinking-water. Effective application of conventional treatment (coagulation, sedimentation, and filtration) will reduce the levels of organic precursors before final disinfection, and avoiding pre-chlorination will result in an overall decrease in the concentration of DBPs. (S. K. Sharma, 2001)

d. problems related to floc formation

Usually in the flocculation process, the floc should settle at the bottom of the tank. However, at times floc tends to float on the surface of the tank thus decreasing the efficiency of the removal process. It might be because of poor maintenance of the tank, not cleaning frequently throughout the working period. (S. K. Sharma, 2001)

e. poor selection of effective sand size

If the sand size is not appropriate with bed pore size, then it might lead to ineffective removal of iron from groundwater. This is usually faced in rapid sand filtration process, one of the iron removal processes. All measurements should be made before selecting the sand size.

f. iron complexation (by silica and humics)

Iron is usually complex with organic matters such as silica and humics. It might be a stumbling block in iron removal process due to its complexity. The pH levels are going to vary, alkalinity would be high, and thus it would be difficult to eliminate the iron from the groundwater. (S. K. Sharma, 2001)

g. inappropriate location for regent dosage

The location of the regent dosage should be well secure enough not to harm or injury anyone. The regents might be hazardous to health, thus a great care should be taken in handling them. (S. K. Sharma, 2001)

h. deterioration of raw water quality over time

Raw water quality will deteriorate if no measures are taken against iron and manganese concentration. It would seriously affect the quality of water with a long presence of concentration of iron and manganese. Therefore it is must that iron and manganese should be removed using the conventional iron removal processes. (S. K. Sharma, 2001)

2.1.1 Oxidation and Rapid Sand Filtration

Oxidation O_2 (Aeration) :The most common oxidant used for oxidation of Fe^{2+} is oxygen but sometimes even stronger oxidants such as potassium permanganate and chlorine are used (Ellis et al, 2000). When using air for oxidation the atmospheric oxygen gets in contact with the dissolved ferrous compounds and oxidizes them to insoluble ferric hydroxides, which is shown by the following chemical formula (Horkeby, 1993)

$$2\ Fe^{2+} + \frac{1}{2}\ O_2 + H_2O \longleftrightarrow 2\ FeOOH + 4\ H^+$$

When aerating the water, the contact between air and water has two effects. The first one makes the carbon dioxide to escape from the water so that pH rises (Hartmann, 2001). The other effect is to increase the amount of dissolved oxygen to assist the oxidation processes. The diffusion of oxygen into water is a bit slow and to accelerate the process, the water can be intensively aerated by adding compressed air or by open aeration (Hartmann, 2001).

Oxidation by adding a chemical reagent has to be followed by an effective filtration because the precipitated particles settle very slowly which make them impossible to remove by sedimentation (Hartmann, 2001). Adding an oxidizing agent is beneficial for iron removal especially where aeration does not show effective result. However, in rural areas these chemicals are often not available or far too expensive for the users. Therefore it is better to use a conventional oxidation system with air to achieve oxidation.

Oxidation Reaction: Fe (II) - dissolved (No oxygen)

Fe (III) - insoluble (Oxygen present)

$$4Fe^{2+} + O_2 + 2H_2O \dashrightarrow 4Fe^{3+} + 4OH^-$$

$$4Fe^{3+} + 4OH^- + 2(n+1)H_2O \dashrightarrow 2(Fe_2O_3\ .nH_2O) + 8H^+$$

$$4Fe^{2+} + O_2 + 2(n+2)\ H_2O \dashrightarrow 2(Fe_2O_3\ .nH_2O) + 8H^+$$

1 mg of Fe requires 0.14 mg of oxygen

High iron concentrations could require a sedimentation step before filtration due to the high content of precipitates that will rapidly clog the filter. Sedimentation is frequently used in water treatment for elimination of suspended particles with a higher density than water (Desjardins, 1997). The particles accumulate in the bottom of the sedimentation tank and the clear water in the upper part of the tank is decanted to a filter.

Rapid Sand Filtration: The filtration rate in a rapid sand filter often varies between 5-15 m3/m2/hour (Hofkes, 1981). The grain size of the filter media vary between 0.4-1.2 mm. Due to this coarse sand, the pores of the filter bed is relatively large and even very turbid water can be cleaned by this filter. However, cleaning the filter is not easy. Since the water penetrates deep in the sand, rapid sand filters has to be back washed. It will not be enough just to scrape off the top layer of the sand to clean the filter. Rapid sand filters are often used to clean groundwater from iron. To assist the filtration process, aeration often is provided as a pre-treatment.

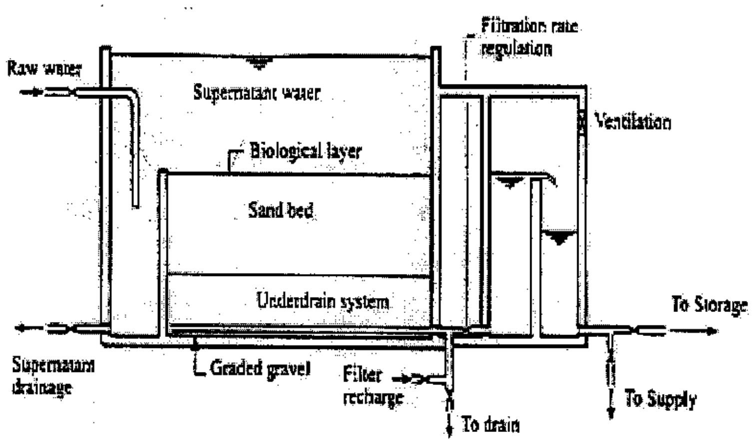

Figure 2-1: Sketch of a Slow Sand Filter (Hanaeus, 1999)

There are different kinds of rapid filters, for example gravity filter, pressure filter and up-flow filter. Gravity flow filters are the most common type of rapid sand filters. Pressure filters have the same construction as gravity flow filters though it is enclosed in a tank to achieve a high pressure. Pressure filters are very complicated in installation, operation and maintenance and are therefore not suitable for small treatment plants in developing countries (Hofkes, 1981). Up-flow filters are well suited for small-scale treatment units but can be difficult and time demanding to clean. Sometimes up-flow filters are used as a pre-treatment step before the water is treated in a rapid filter with a gravity flow or a slow sand filter (Johansson et al, 2002).

Adsorption Oxidation mechanism: The process by which molecules, colloids, or particles adhere to the surfaces by physical action but without chemical reaction.

a. No pre oxidation of iron(II)
b. Removal of iron in iron(II) form
c. iron(II) adsorption onto filter surface/flocs
d. Oxidation of adsorbed iron (II) and creation of new surface for adsorption.

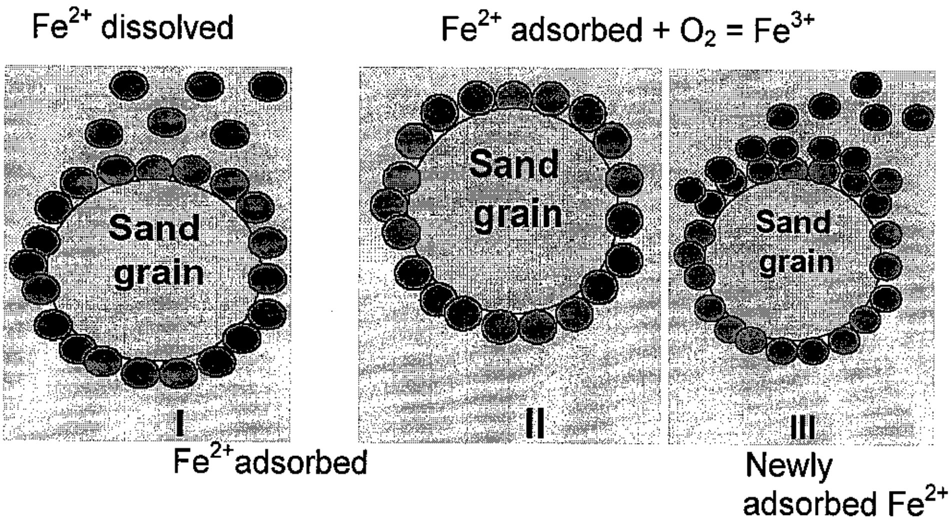

Figure 2-2: Sketch of Adsorption-Oxidation Mechanism (S. K. Sharma, 2001)

2.1.2 Lime Treatment

The addition of lime (Ca) and soda ash (Na_2CO_3) reduces the level of calcium and magnesium and is referred to as "lime softening." The purpose of lime softening is to precipitate calcium and magnesium hydroxides (hardness) and then clarify the water. The process is inexpensive but only marginally effective, usually producing water of 50 to 120 ppm (3 to 7 gpg) hardness (Cheremisinoff, 1997).

Disinfection: Disinfection is one of the most important steps to municipal water treatment. Usually, chlorine gas is fed into the supply after the water has been clarified and/or softened. The chlorine kills bacteria. In order to maintain the "kill potential", an excess of chlorine is fed into the supply to maintain a residual. The chlorine level must be constantly monitored to assure that no harmful levels of chloramines or chlorinated hydrocarbons develop (Osmonics, 1997).

pH adjustment: Municipal waters may be pH adjusted to a pH of approximately 7.5 to 8.0 to prevent corrosion of water pipes, particularly to prevent dissolution of lead into the water supply. In the case of excessive alkalinity, the pH may be reduced by the addition of CO_2 (Osmonics, 1997).

2.1.3 Oxidizing Filters (Manganese green sand)

These filters are often referred to as iron filters or red water filters. Oxidizing filters are most effective in water with a pH of 7 or above. If water is acidic (pH below 7), a chemical feed pump may also be needed. Oxidizing filters use a"greensand" resin bed to oxidize iron and manganese that are in solution. As the water flows through the resin bed, the iron and manganese are oxidized and changed from their soluble to an insoluble form (Hairston, 1995). These minerals then become trapped as rust particles within the greensand filter bed. The greensand media will also act as a filter and catch iron and manganese precipitates that have been oxidized before reaching the filter. If iron and manganese are very high (more than 1mg/L) or if water is acidic (pH below 7), a strong oxidizing substance must be applied prior to filtration (Plowman, 1989)

Super chlorination is the process most commonly used to oxidize iron and manganese and to adjust the pH. At a pH of 7 or above, iron changes more readily from its soluble to its insoluble form, this can then be removed by filtration. This process will also kill any iron bacteria, but the excess chlorine may not be filtered out. Some of these units are effective for iron and manganese removal in combined concentrations up to 10 mg/L (Hairston, 1995). Greensand can also be effective in removing sulfur compounds (primarily hydrogen sulfide) in concentrations up to about 5 mg/L. Because oxidation occurs as water flows through the filter bed, much of the precipitate is filtered out near the discharge side of the greensand bed. If backwashing is not thorough, the precipitated iron and manganese can be expelled from the filter in large masses and cause a disgusting discharge from a faucet or ruin a washer load of clothes. This type of filter will not tolerate iron bacteria because the slimy material that is produced coats the greensand and fouls it (Plowman, 1989) Oxidizing filters must be regenerated with a new solution of potassium permanganate when the oxygen is depleted. The condition of the water, the size of the unit, and the amount of water consumed will all affect how quickly the oxygen is depleted.

2.1.4 Fine Bubble Aeration

Aeration is a step in wastewater treatment where air is added to wastewater for mixing purposes and to enhance biological growth. The purpose of aeration is to dissolve oxygen into wastewater so that the microorganisms can utilize it while they break down organic material.

Fine bubble aeration is a subsurface plant upgrades form of diffusion in which air is introduced in the form of very small bubbles to aid or enhance the treatment of wastewater. Air flows from a pipe into diffusers located at the bottom of a tank. These diffusers have numerous small openings (known as pores) through which air flows into the wastewater in the tank. In the past, various diffusion devices have been classified as either fine bubble or coarse bubble based on how efficiently they transferred oxygen to the wastewater. Since it is difficult to clearly distinguish between fine and coarse bubbles, diffused aeration systems have been classified based on the physical characteristics of the equipment.

In a fine bubble aeration system, several diffusers are mounted or screwed into a header pipe that may run along the length or width of the tank or on a short manifold mounted on a movable pipe. These diffusers come in various shapes and sizes, such as discs, tubes, domes, and plates.

The common types of coarse bubble diffusers are fixed orifices, valve orifices, and static tubes. The bubble size of these diffusers is larger than the porous diffusers, thus, lowering the oxygen transfer efficiency (OTE). Fine pore diffusers (discs, tubes, domes, and plates) are usually made from ceramic, plastic, or flexible perforated membranes. Although many materials can be used to make fine pore diffusers, only these few are being used due to cost considerations, specific characteristics, market size, and other factors.

2.2 Evaluation of Chicha Water Treatment Plant, Kelantan.

The 'Air Kelantan Sdn. Bhd.' is the latest water treatment plant in Kelantan. It was designed to accumulate a capacity of 60MLD – 80MLD. 'Air Kelantan Sdn. Bhd.' is responsible in operating high quality of water distribution at Kelantan. There are 32 water plants in Kelantan with their own water source each. From the latest researches, raw water came from two sources; 50% from underground water and 50% from the surface water (river). For this plant, it had it source from 7 wells. There are 'Chicha plant', 'Kenali well', 'Pasir Hor well', 'Pasir Tumboh well', 'Padang Penyadap well', ' Kubang Kerian well' and ' telaga Seribong'. The water form this plant is distributed to certain areas, which are 'Kota Bharu', ' Tanah Merah', 'Tumpat', 'Kuala Krai', 'Machang', 'Bachok', 'Pasir Mas', 'Jeli', 'Pasir Putih' and 'Gua Musang'.

Figure shown below summarizes the overview of the Chicha plant.

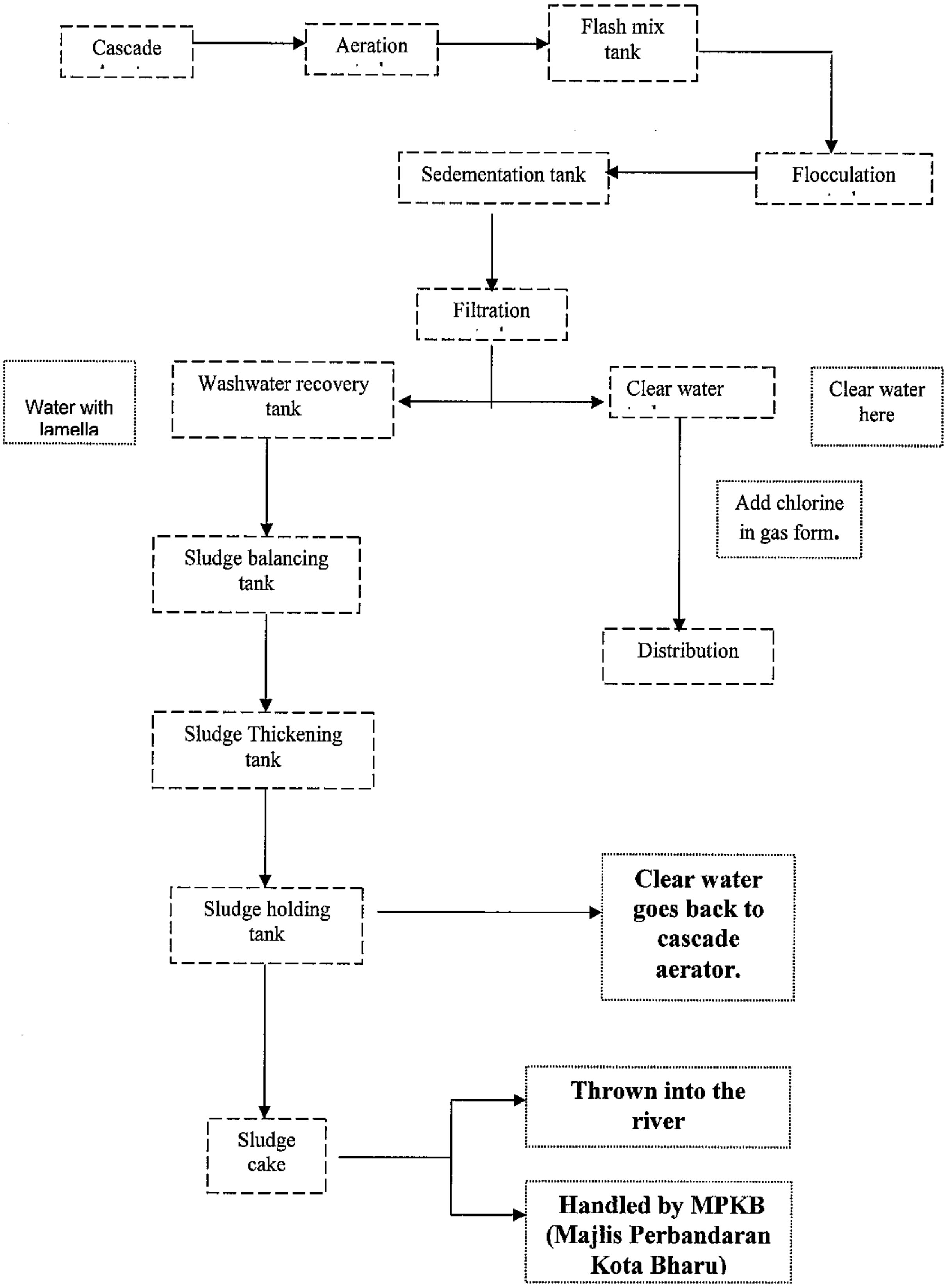

Figure 2-3: Chicha Water Treatment Plant Flow Processes

The important elements of this plant for the project are the first four stages of treatment. These for stages are aeration, addition of alum, coagulation, sedimentation and also post lime stage.

2.2.1 Cascade Aerator and Aeration Tank

There are two stages carried in the aeration plant. The first one is the cascade aerator, while the second one is the fine bubble diffused aerator (FBDA). The second one is the stage of aeration to oxidize excessive soluble iron in the raw water that exceeds the limit that the cascade aerator can handle.

At the end of the cascade aerator inlet chamber, pre-lime will be added to adjust the pH in order to obtain the optimum coagulation. The other thing to be added is Potassium Permanganate. If the raw water flow rated more than 500 m^3/h, pre-lime will be used, but if there is raw water flow rated more than 300 m^3/h, the Potassium permanganate will be used. Then, the raw water sample will take from the cascade aerator inlet chamber to be analyzed in laboratory. There are two units of sampling pump, one unit on duty and another one on standby that will deliver raw water to the clarify bowl and laboratory. Every 24 hours, these two pumps will alternately being used.

There are two ways of controlling the aeration air blower which are remote or local. When raw water flow rate is more than 500 m^3/h for 60 sec, auto mode condition air blower pump will start and will stop when it is less than 500 m^3/h for 60 sec. pH is about 5 in aeration tank, while concentration of lime added is about 5 %. Purity of lime is about 99.4 %, and also the size of aeration tank is 314 m^3

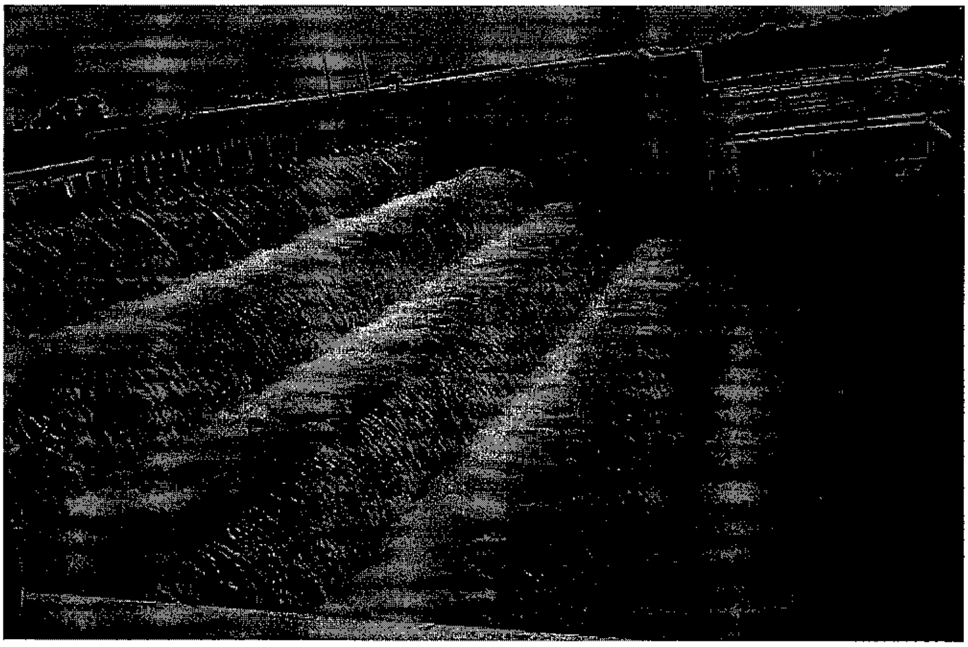

Figure 2-4: Cascade Aerator

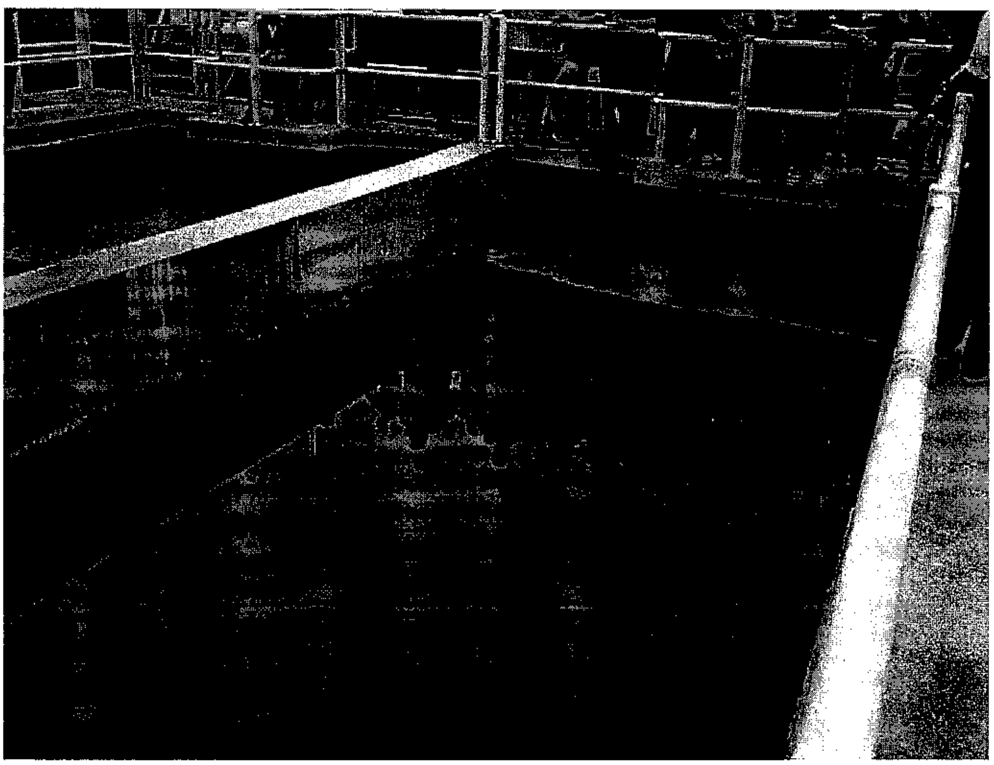

Figure 2-5: Aeration Tank

2.2.2 Flash Mixing Tank

Intense mixing or agitation is required to disperse the chemicals uniformly throughout the tank and to allow adequate contact between the coagulant and the suspended particles. By the time the water leaves the rapid-mix basins, the coagulation process has progressed sufficiently to form microfloc. Therefore, alum or aluminium sulphate is added in the form of liquid in order to encourage flocculation process. Polymer needs to be added into the water in order to increase the rate of flocculation after considering the overall design of the plant. After adding the chemicals, the water will then turn into red in color because of the addition of lime and chlorine. It takes 45 minutes to 1 hour for suspended colloidal to floc. Concentration of alum is about 20 ppm, while purity is about 8 %.

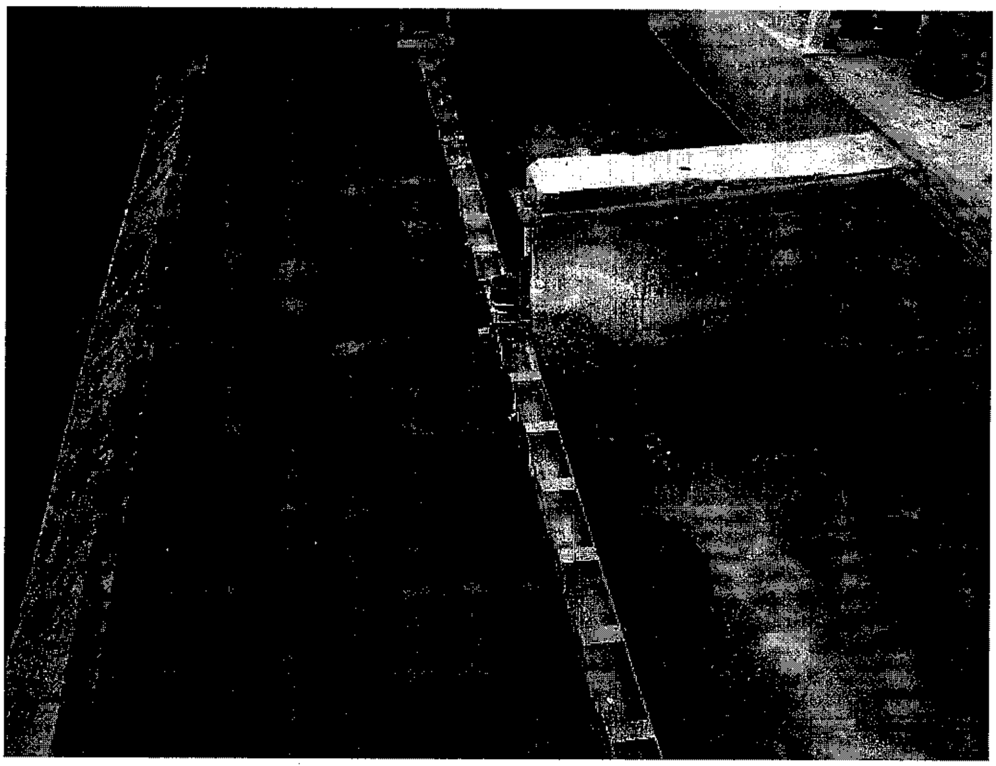

Figure 2-6: Flash Mixing Tank

2.2.3 Flocculation Tank

Five beds exist. No stirring activity in this tank because calm water is needed for the flocculation process or let the floc to settle. In the flocculation process, destabilization of the suspended and colloidal particles in the ground water happens when the water is mixed with specific chemicals. As a result, these particles start to accumulate to become floc. By adsorption of more colloidal and suspended particles the mass of floc tend to become larger. The floc will settle and become sediment at the bottom of the tank. After that, the sludge is sent to the sludge drying beds and dried there. The sludge drying beds are sludge balancing tank, sludge thickening tank and sludge holding tank. These tanks are built of mild steel and coated with anti-corrosive protecting paint. Detention time is about 15 min.

2.2.4 Sedimentation Tank

The sedimentation tank in this water treatment plant is a gravity separator that utilizes the difference in specific gravity of particles in order to settle out solids and sludge in the wastewater stream.

a) Water that enters into the tank contains suspended or colloidal particles
b) These particles or sediments settle to the bottom of the tank and form sludge, which is then sent to the outlet by using scrappers

The process depends very much on the flow rate of water. Therefore, slanting lamella is placed at the bottom of the tank. This slanting lamella will slow down the water flow rate, where the water comes from the bottom of the tank. The degree of slanting can influence the water flow rate. At the end of the process, the water will flow slowly through this tank until it reaches the other end of the tank. The floc will settle through gravitational force at the bottom of this tank. Sometimes treatment plant has a problem in this stage when floc doesn't settle. One of the possible causes might be that poor cleaning of the sedimentation tank and also too much addition of alum. The type of clarifier used is inclined type of clarifier.

2.2.5 Contact Tank

In contact tank, the lime is again added (post-lime dosed) to balance up the pH of the water up to (7.5 – 8.5 NTU). Another reason is because of manganese concentration present is quite high. Currently treatment plant has a manganese concentration problem which is quite high. It's a bit of concern for the administration of this plant is high manganese concentration because it is harmful to health if this problem isn't tackled. Another worrying factor is alkalinity of water. Alkalinity of water is quite high at about 39, that means too much of bicarbonate. Therefore, the pH data obtained from the plant might not be accurate due to high alkalinity of water. Thus it might affect overall performance of the plant.

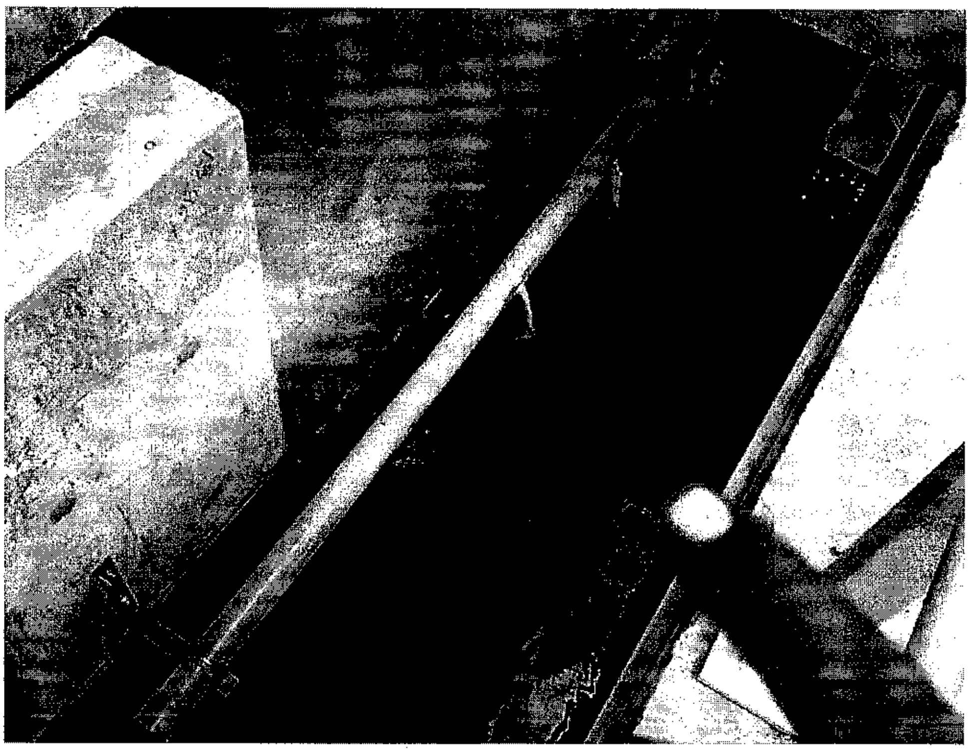

Figure 2-7: Post Lime Process

2.2.6 Experimental Data Analysis on Chicha Water from 14-30 Sep, 2004

1st Graph Sequence: pH

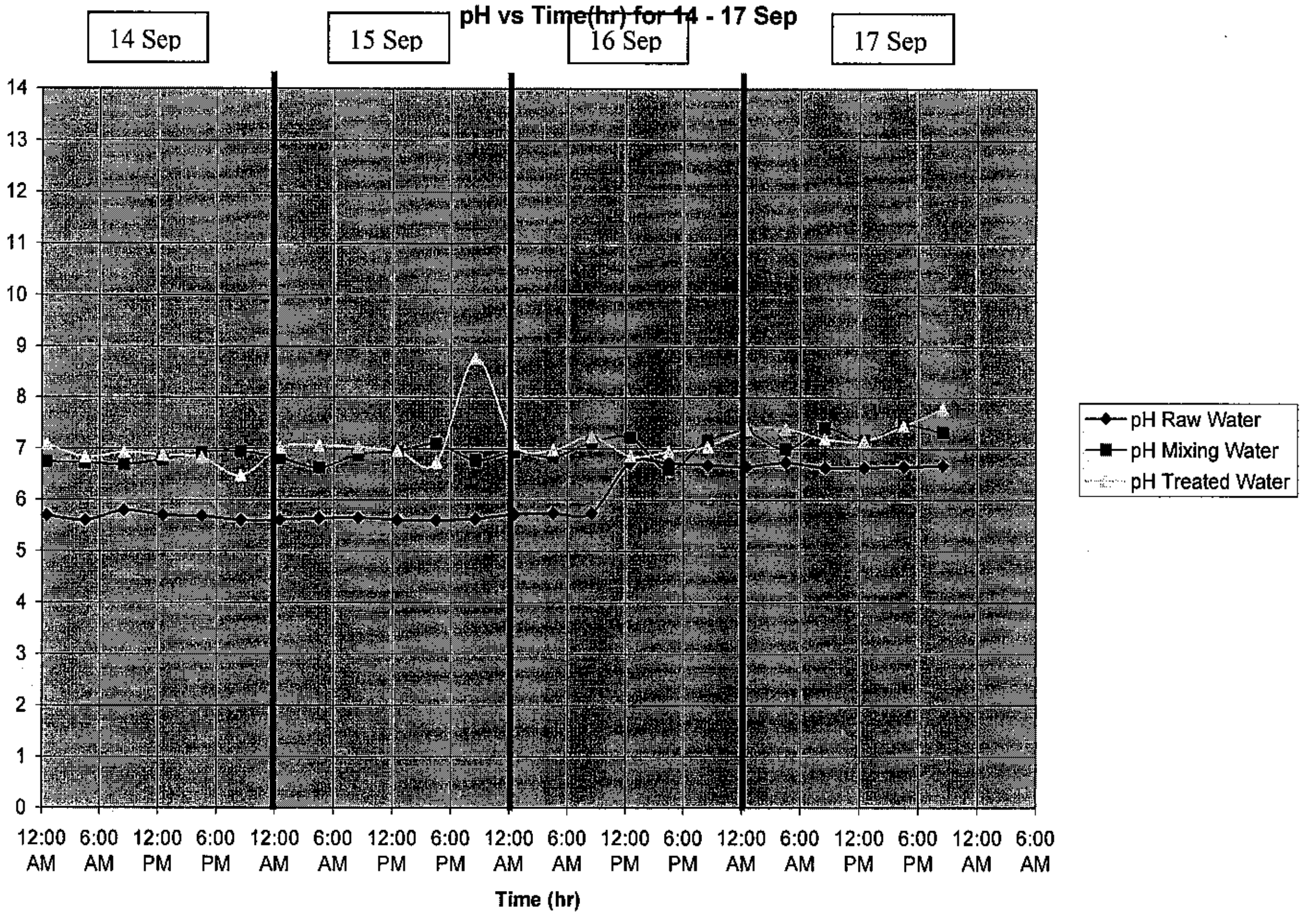

Figure 2-8: pH vs Time (hr) for 14-17 Sep

The data shows various pH variations for every removal stage in the plant. pH raw water reading is the lowest because it is pure groundwater with no chemical additions. However, pH increases in latter stages due to addition of chemicals throughout the process. The main reason to adjust the pH is to maintain the stable, constant value throughout the removal process. Usually pH varies if the added chemical concentration is low or high than its proportion. The main point is to maintain pH reading of 7. Reminder is that WHO standard for pH is between ranges of 6.5 – 8.5. The readings for pH mixing and treated water are almost the same in the region of 7.

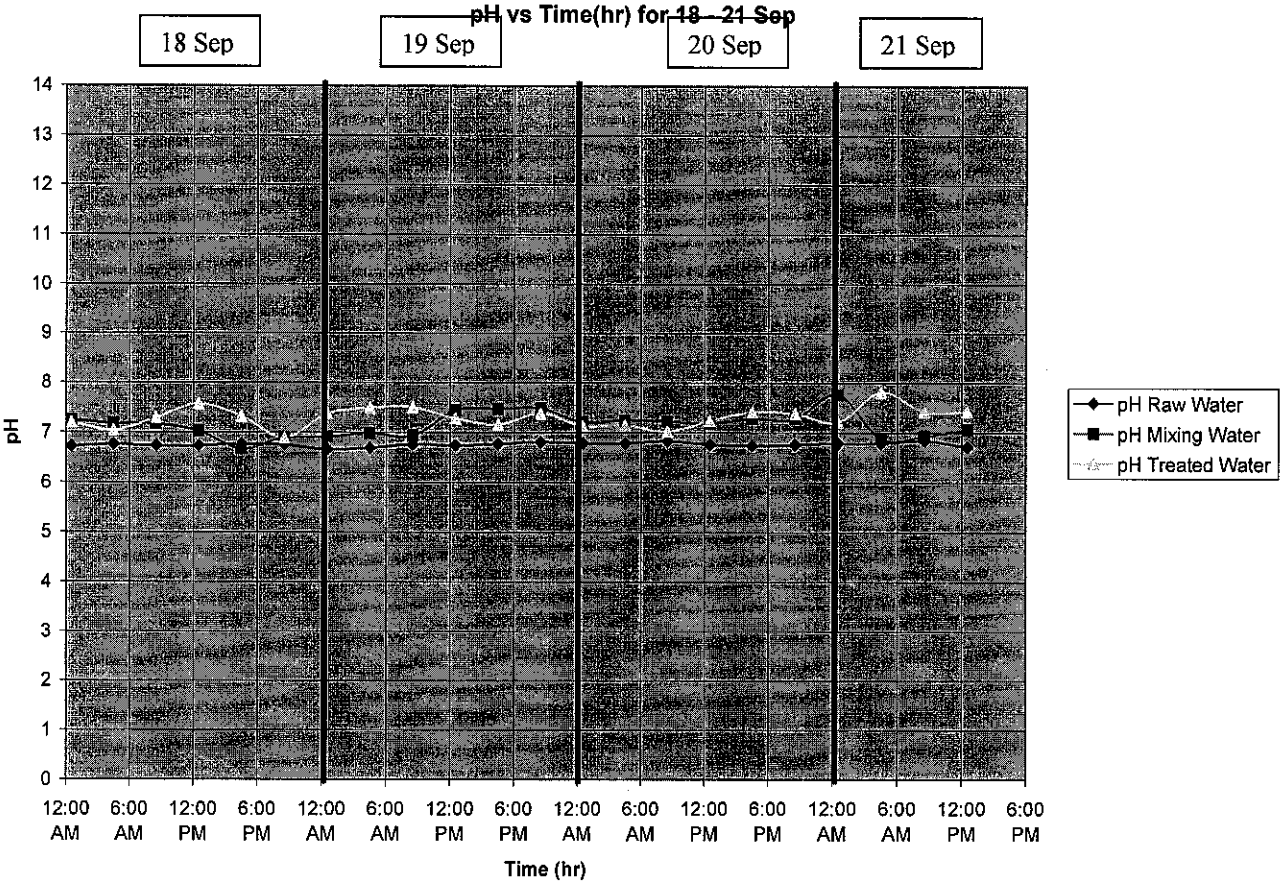

Figure 2-9: pH vs Time (hr) for 18-21 Sep

The data for these four days are more stable and linear. All of them are in the region of pH of 7. Once again pH reading for raw water is the lowest than the others. The linear readings also show that plant performance was at high standard in these four days. Accurate pH results indicate the efficiency of the removal processes.

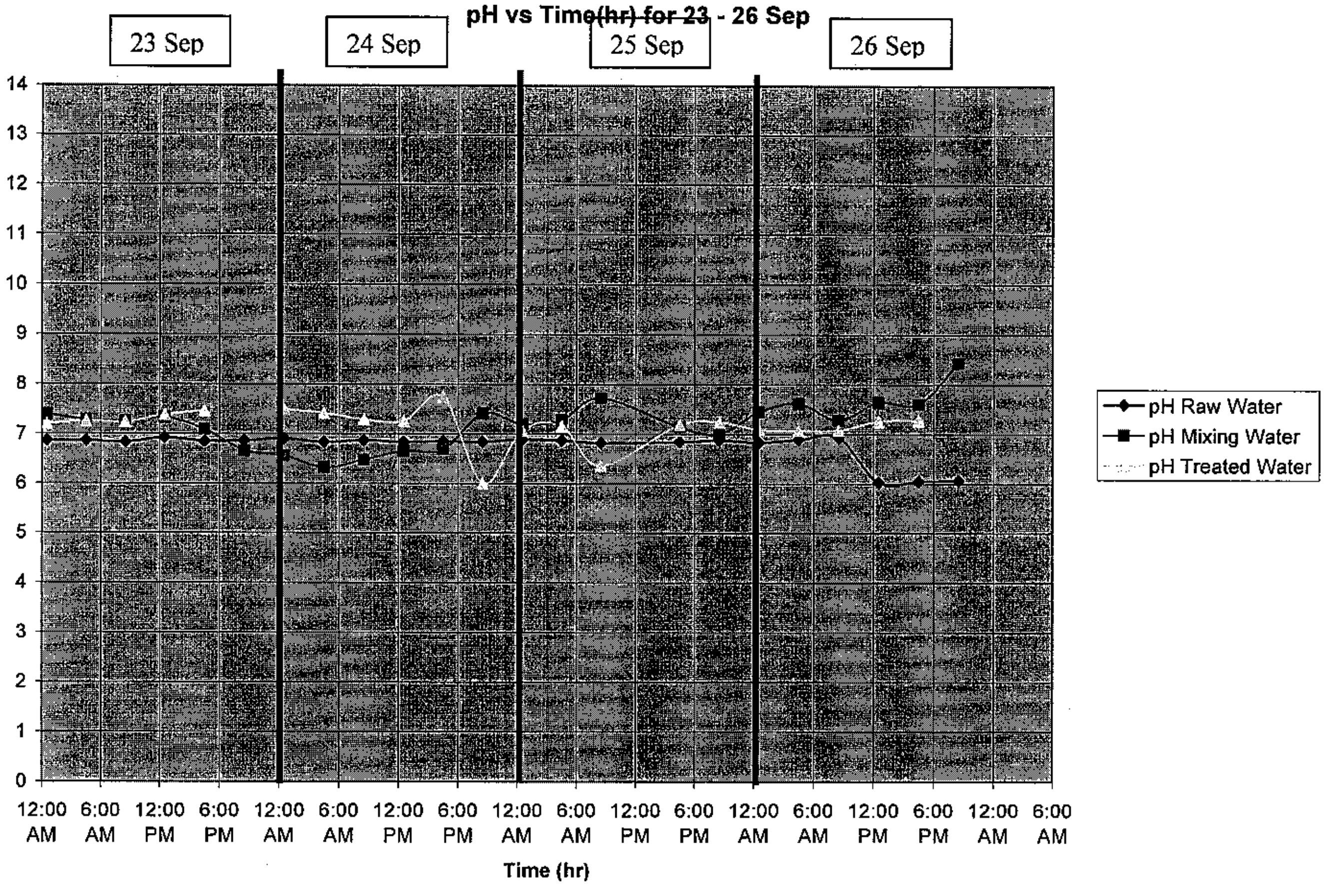

Figure 2-10: pH vs Time (hr) for 23-26 Sep

The data are not that accurate for these four days. As shown above, reading for pH mixing water and treated water vary and inconsistent. It may be due to various proportions of chemicals added in these stages. If the chemical additions aren't carefully checked, the results may vary. For pH raw water; the reading is the same throughout the period except for the 26th Sep where it decreases to pH reading of 6. However, all pH readings are in the region of 7.

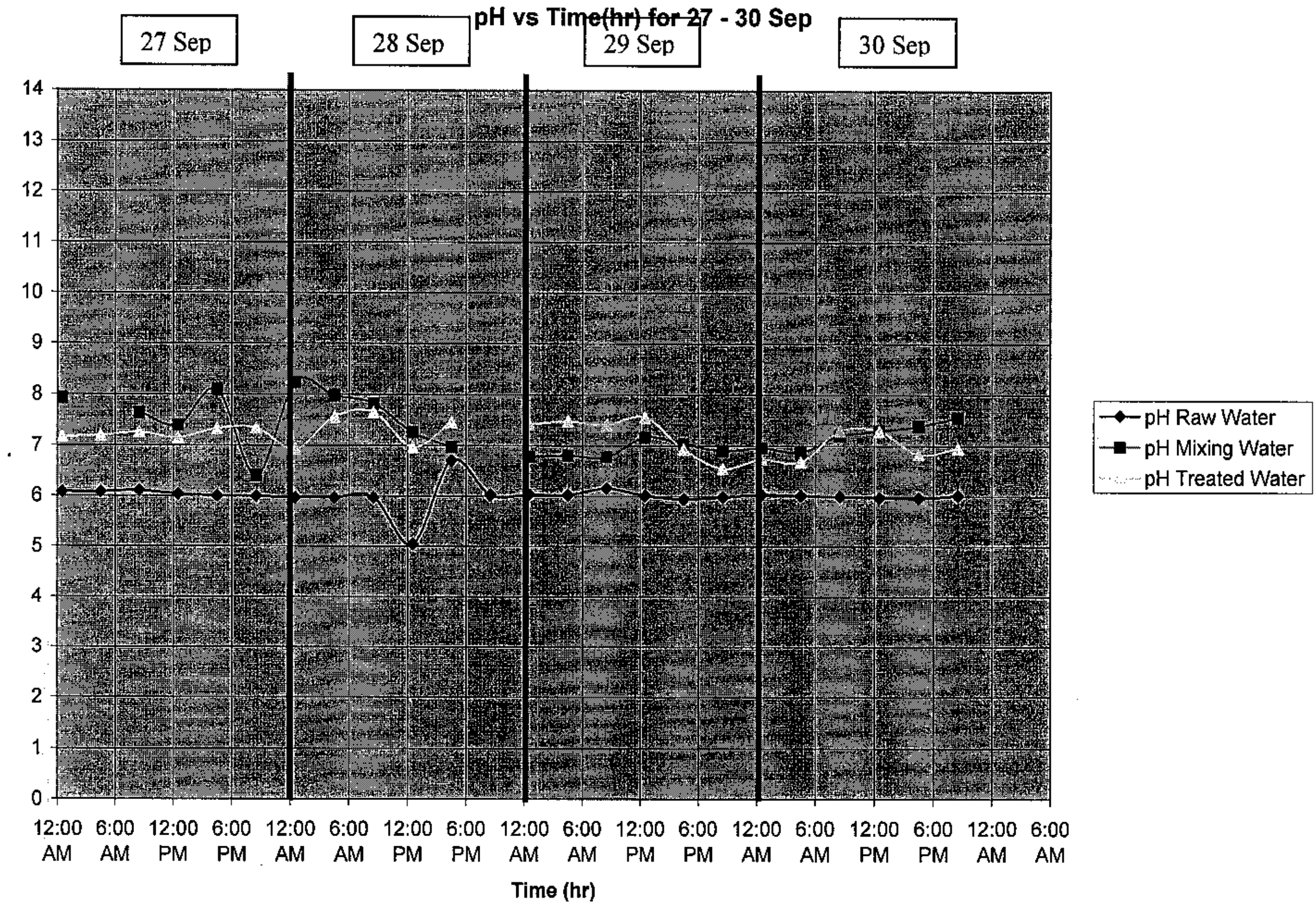

Figure 2-11: pH vs Time (hr) for 27-30 Sep

The data shown above aren't accurate as previous results. The readings aren't linear with many sudden jumps. pH raw water reading is at 6, while other readings aren't stable or missing. pH mixing water readings aren't that good with many jumps. It shows that chemical additions weren't in correct proportions in that stage. pH treated water readings are in region of 7 but also with some jumps. The results are still positive due to the fact that pH treated water reading is in region of 7.

2nd Graph Sequence: Turbidity

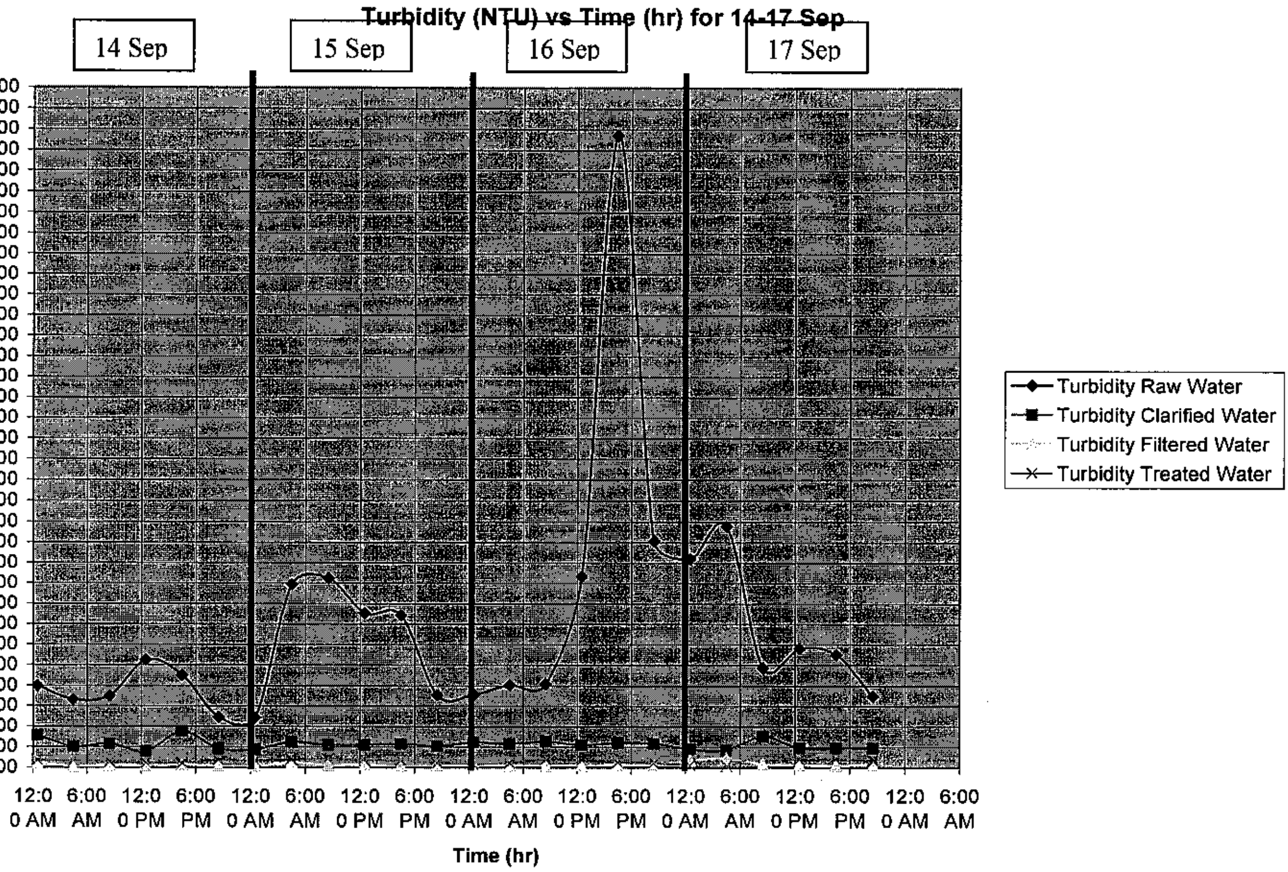

Figure 2-12: Turbidity (NTU) vs Time (hr) for 14-17 Sep

Turbidity is a measure of the light - transmitting properties of water, is another test used to indicate the quality of natural waters with respect to colloidal and residual suspended matter. It should be noted that the presence of air bubbles in the fluid will cause erroneous turbidity readings. Obviously the turbidity readings for raw water would fluctuate and also would be very high especially for 16 Sep since no treatment is done yet. However readings decrease drastically in latter stages because of major addition of chemicals such as lime and alum. Coagulation stage would prove crucial to reduce the turbidity. Treated water turbidity reading is almost low as 0 NTU which is a positive result. The methods prove to be successful to reduce the turbidity of the water with major chemical additions.

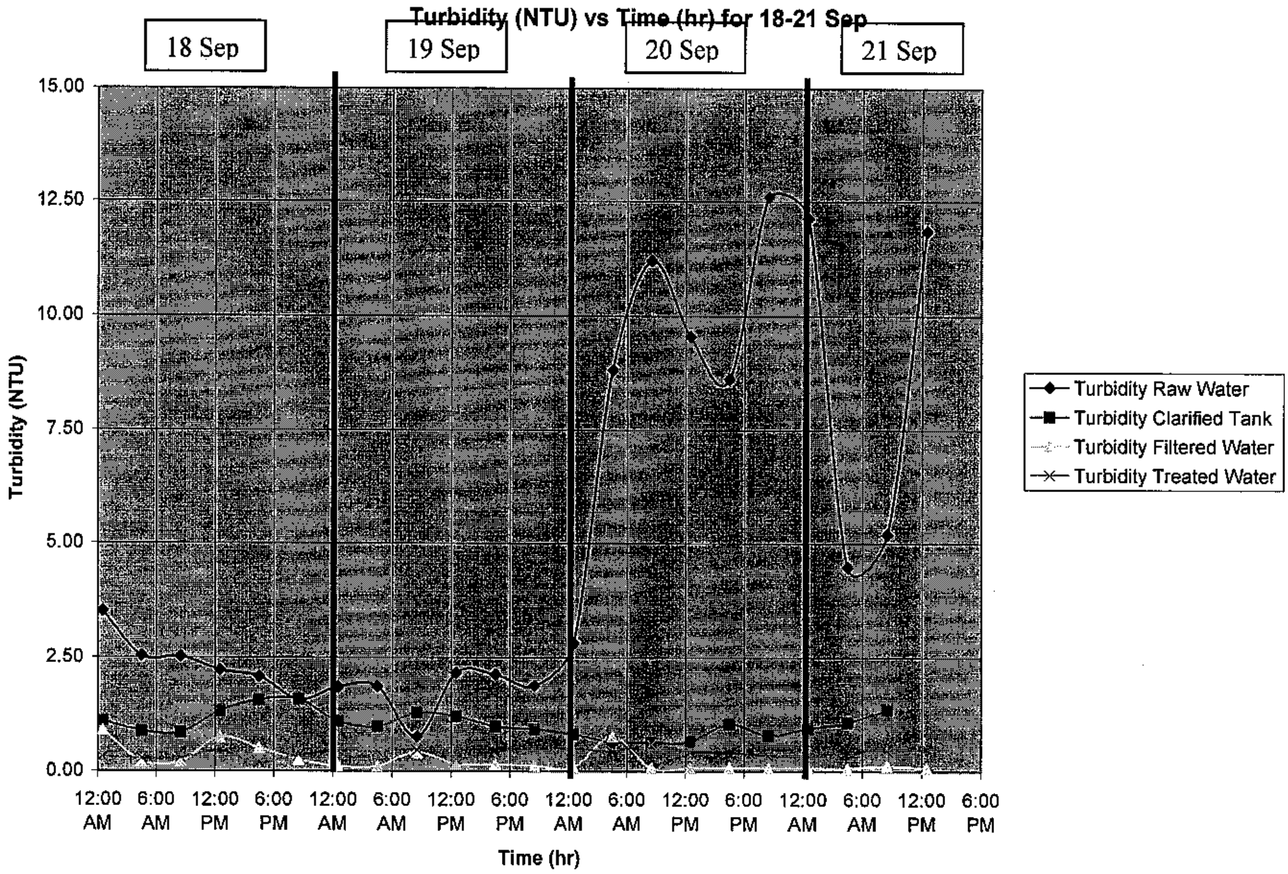

Figure 2-13: Turbidity (NTU) vs Time (hr) for 18-21 Sep

Once again, raw water turbidity readings are very high, with many jumps. The results for raw water are quite terrible given that it always change. However, the positive aspect is that it decreases in latter stages of process. It shows an effectiveness of the added chemicals to reduce the turbidity. Note that turbidity reading for treated water is not as low as 0 NTU this time. It may be due to presence of air bubbles in the fluid which causes erroneous readings or poor handling of the chemical dosage in the process. However, it's still positive result since it's not that high.

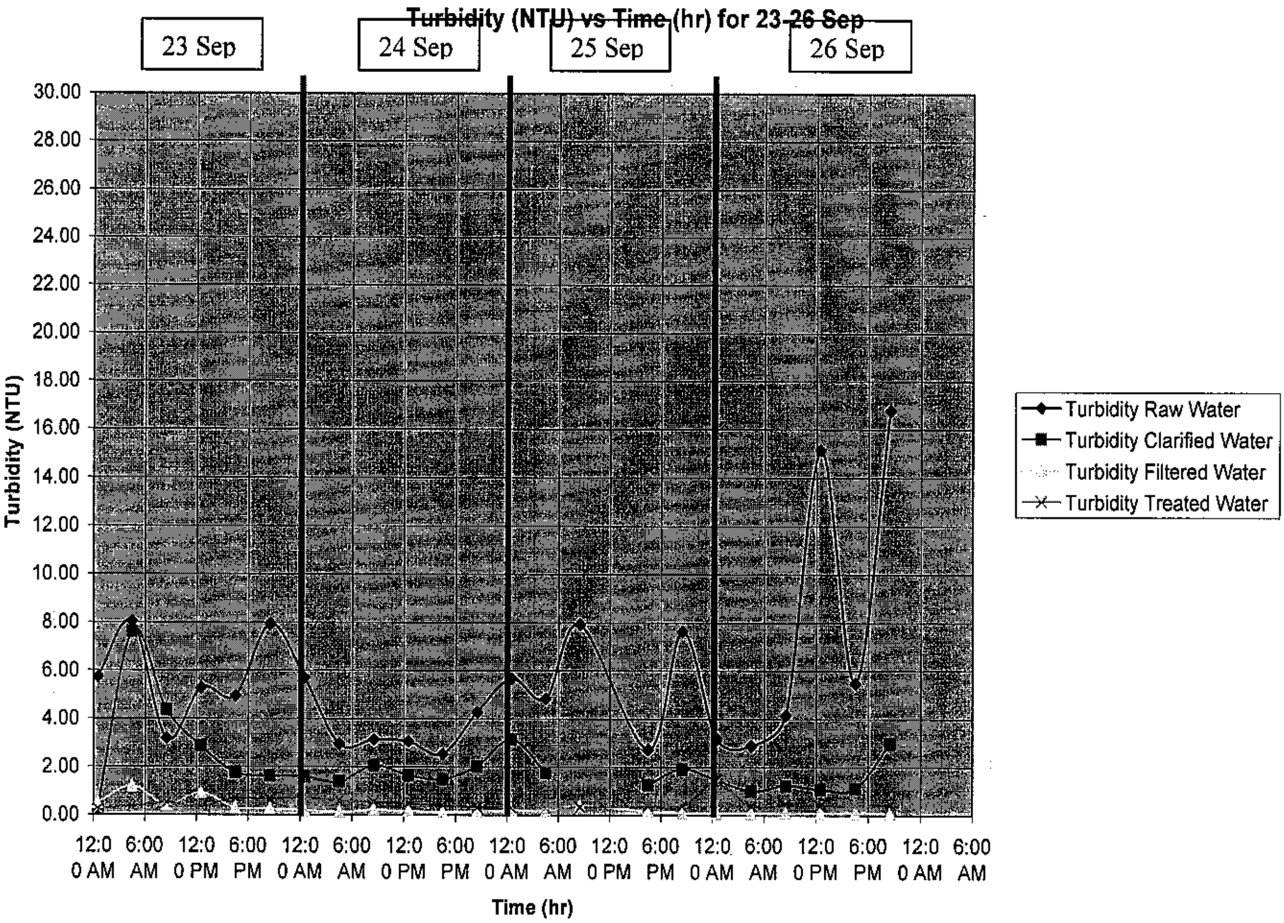

Figure 2-14: Turbidity (NTU) vs Time (hr) for 23-26 Sep

As shown above, the turbidity readings for raw water are very high once again. It shows the presence of particles in raw water. There are also some other erroneous readings such as for turbidity reading for clarified water for 23 Sep. It has a sudden jump and decrease to follow. It may be due to poor maintenance of chemical additions on that day since other readings for others days are more consistent. The turbidity readings for filtered and treated waters are as low as 0 NTU which is a positive result for the performance of the plant.

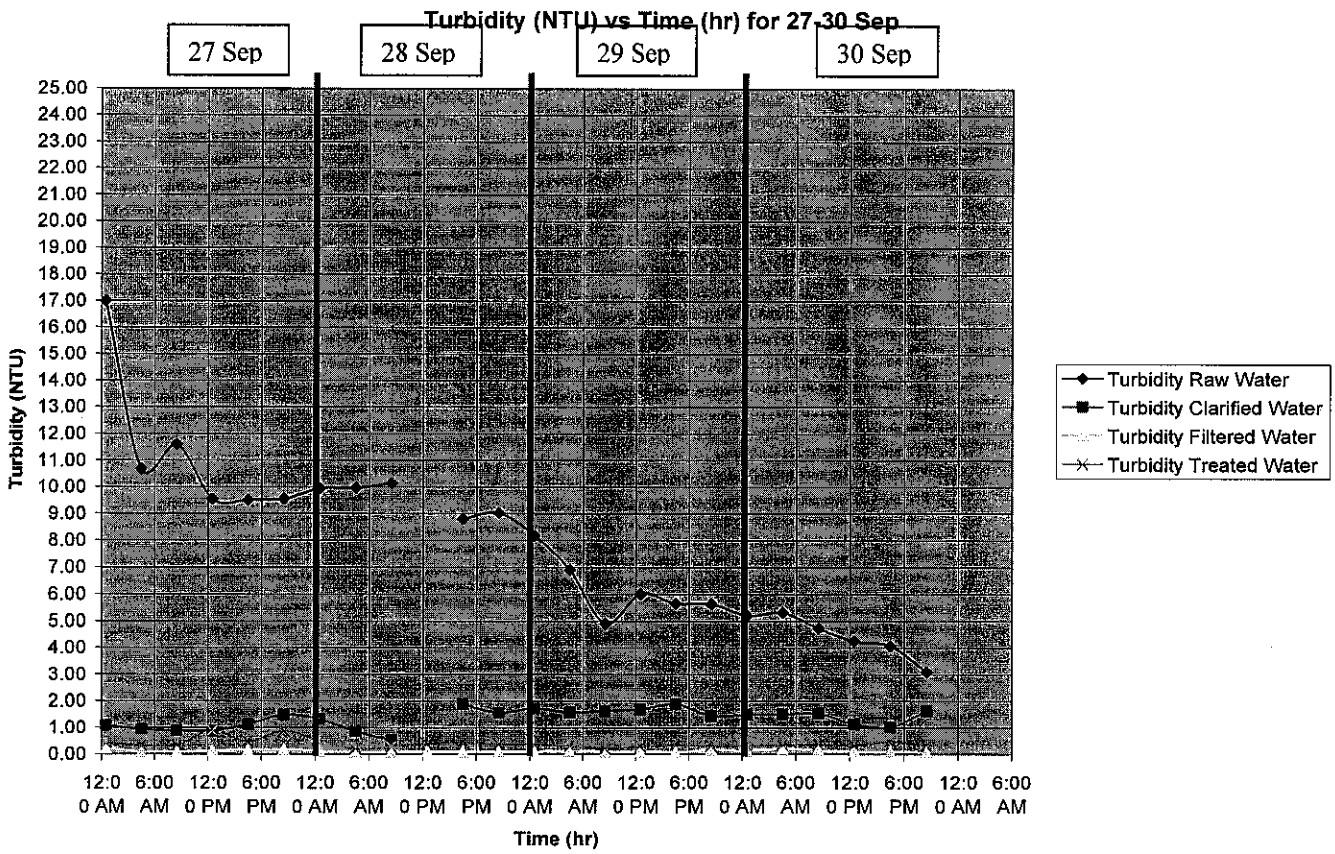

Figure 2-15: Turbidity (NTU) vs Time (hr) for 27-30 Sep

Once again, the turbidity readings for raw water are very high with many variations. Starting from 27 Sep, it decreases till 30 Sep which is an odd result if we compare the other days. However, there is no change in drastic decrease of turbidity readings in latter stages of the process. Chemical additions such as lime and alum prove to be very effective and efficient. Turbidity readings for filtered water and treated water are as low as 0 NTU. The plant's performance is quite positive and impressive in the decrease of turbidity which is a physical characteristic of water.

3rd Graph Sequence: Iron Concentration

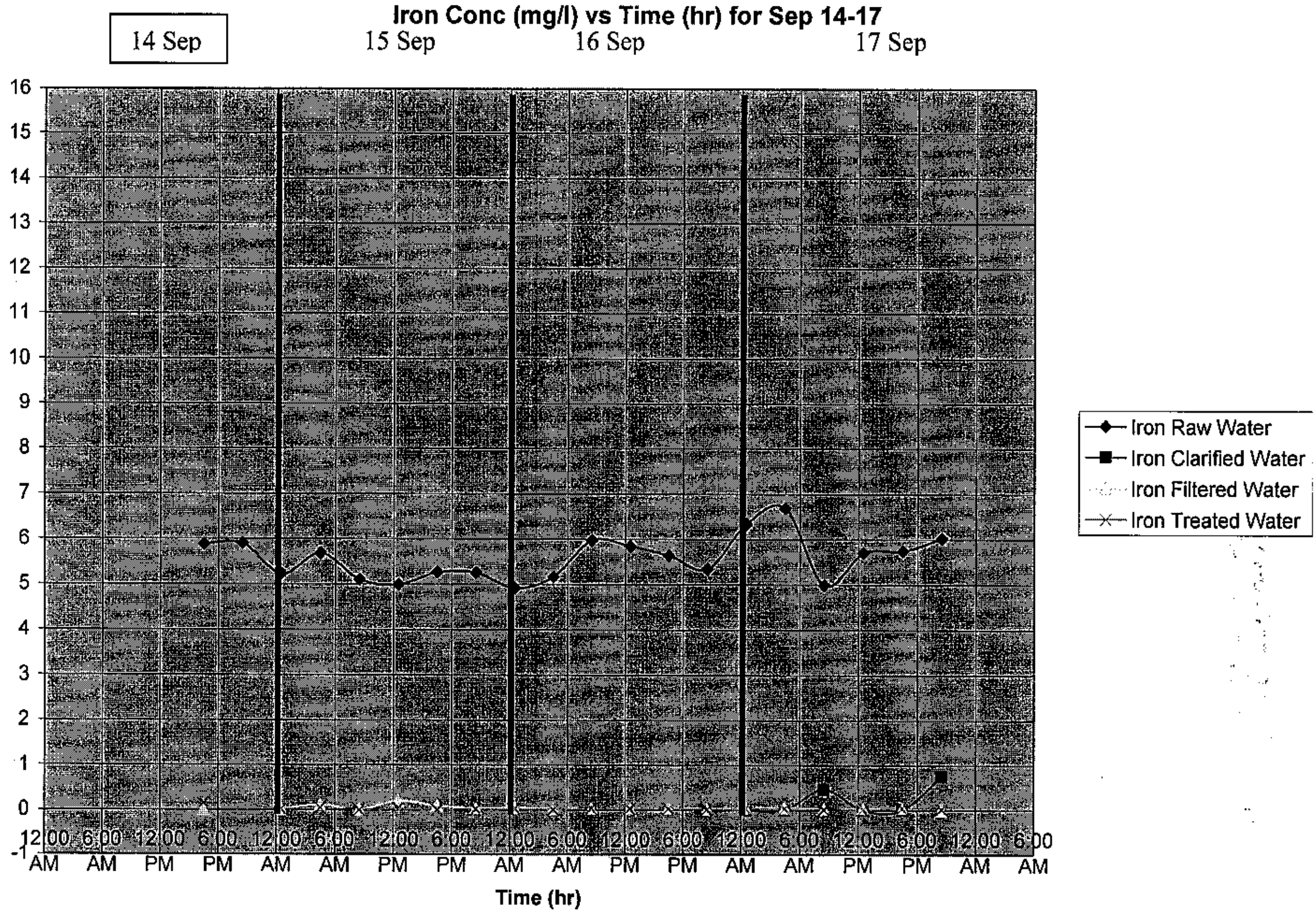

Figure 2-16: Iron Conc (mg/l) vs Time (hr) for Sep 14-17

As shown above, the iron concentration readings for raw water are very high. Once again, it shows that it is essential to use iron removal methods for groundwater. The standards set by WHO is 0.3 mg/l, whereas for raw water it is in the region of 6 mg/l which is totally unacceptable. However, in the latter stages the readings decrease to a region of 0. It shows the effectiveness of chemical additions throughout the processes. The readings are linear and low which is a positive result. Reading for treated water is almost or equal to 0 which shows efficient performance of the plant and its compliance with WHO standard of 0.3 mg/l.

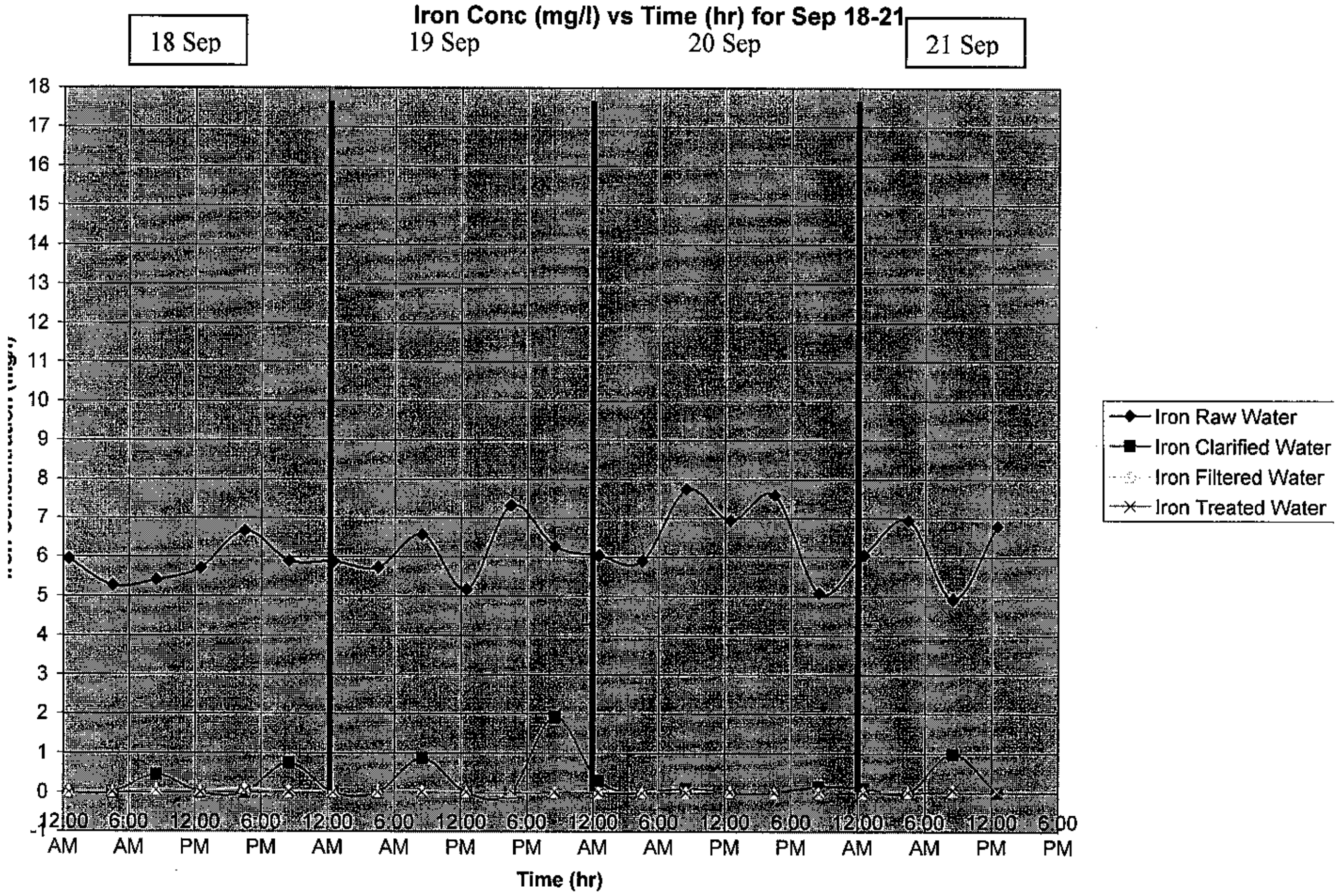

Figure 2-17: Iron Conc (mg/l) vs Time (hr) for Sep 18-21

Once again, the iron concentration readings vary with many jumps showing non-linear, inconsistent results. The reading for raw water is in the range of 6-7 mg/l which is totally unacceptable. Reading for clarified water isn't as good as in previous graph. It has many jumps showing inaccuracy and inconsistency especially for 19 Sep readings. For the latter stages, readings are accurate and positive; it's in the region of 0 mg/l which is acceptable.

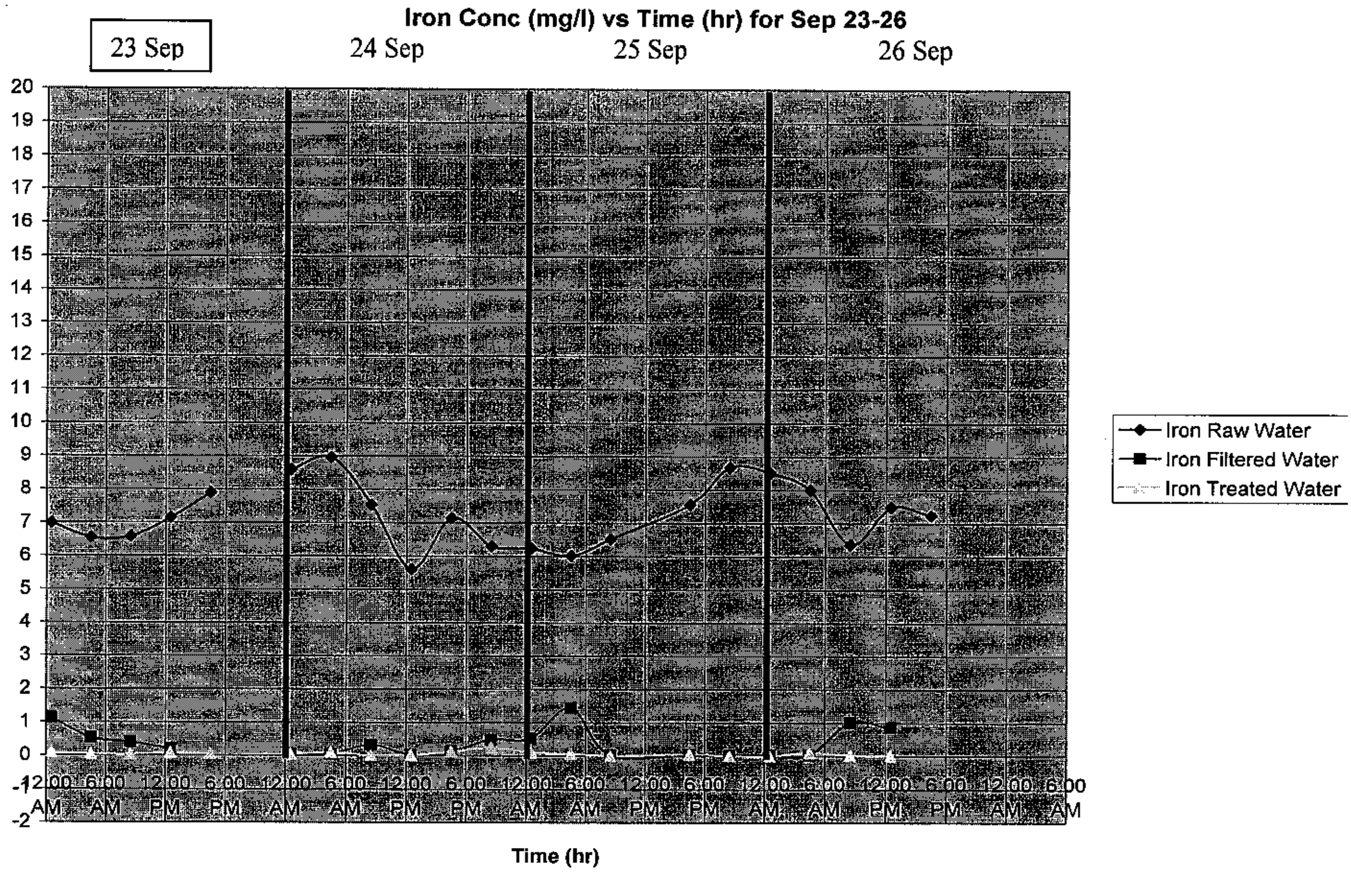

Figure 2-18: Iron Conc (mg/l) vs Time (hr) for Sep 23-26

As shown above, raw water iron concentration readings are the highest than the others. Unfortunately, there was no sufficient available data for clarified water readings. However, other results are enough to conclude that processes are operating effectively. Iron treated water readings are almost as 0 mg/l which is acceptable. As long as, the readings are below the standard set by WHO which is 0.3 mg/l it would be a positive result.

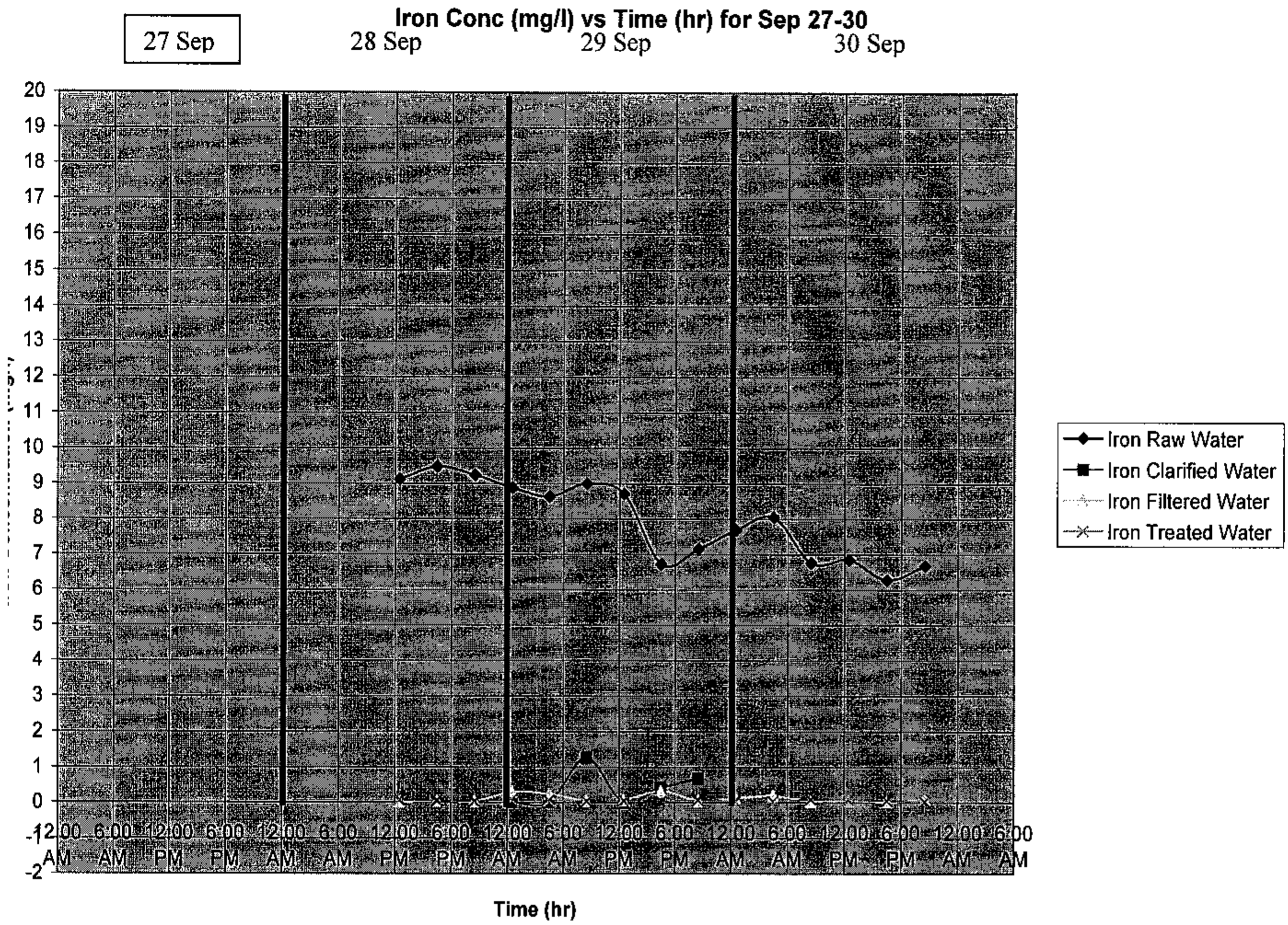

Figure 2-19: Iron Conc (mg/l) vs Time (hr) for Sep 27-30

Data isn't available for 27 Sep, therefore it was impossible to come with up a graph. Raw water readings are again the highest which is no surprise. Other readings are in the region of 0 mg/l which is a very good result. It shows that plant operations were of high standard in these 3 days.

4th Graph Sequence: Manganese Concentration

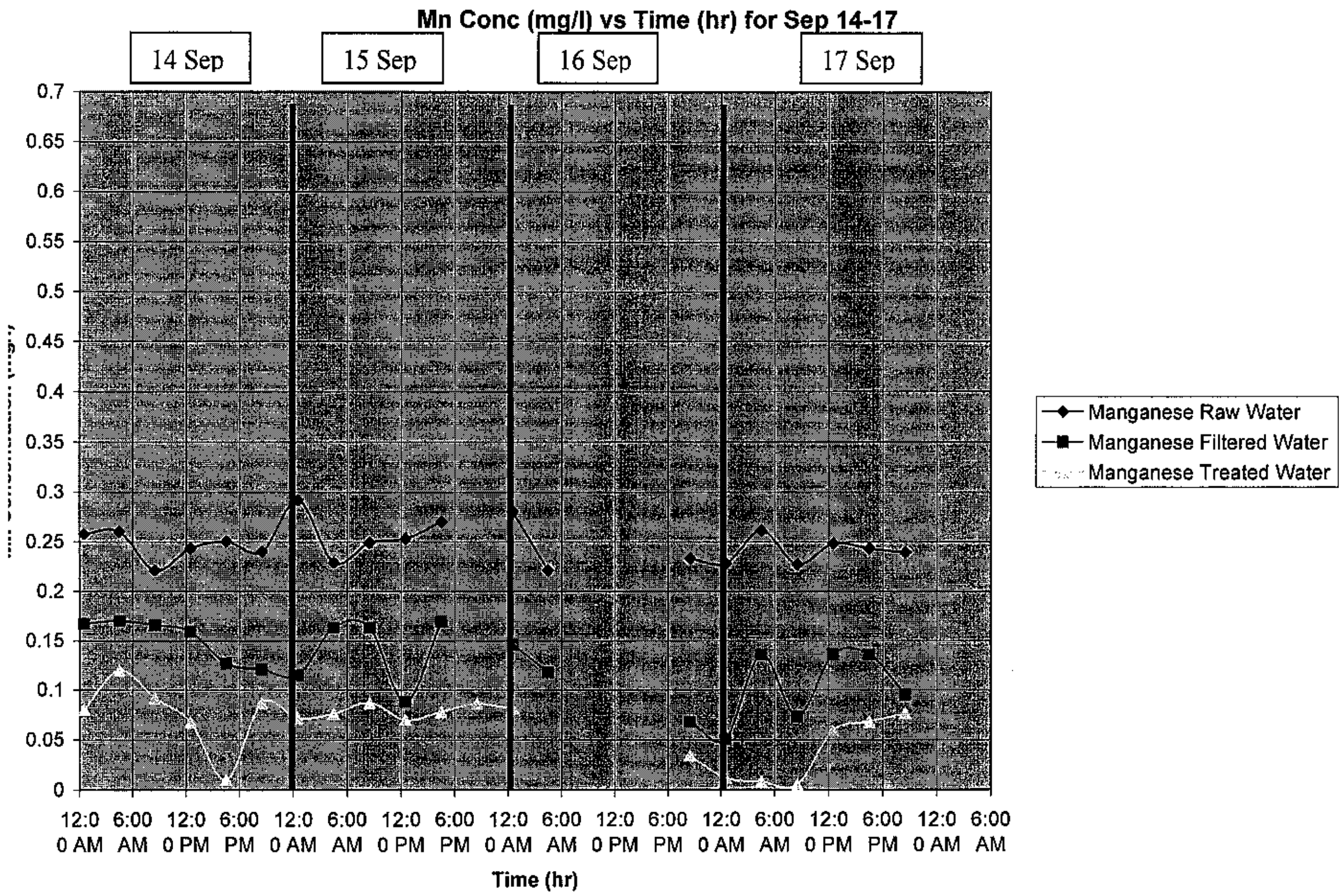

Figure 2-20: Mn Conc (mg/l) vs Time (hr) for Sep 14-17

As shown above, manganese concentrations are quite high for all processes. Manganese raw water reading is the highest averaging in the region of 0.25 mg/l. However the main problem is the reading of treated water. A reminder that standard set by WHO on manganese concentration shouldn't exceed 0.05 mg/l. The manganese treated water reading is above the 0.05 mg/l value, which violates the standard regulations. The high value is probably caused by poor maintenance of the tanks and may be extra addition of chemicals. This is the main challenge for the plant and it should take appropriate actions immediately.

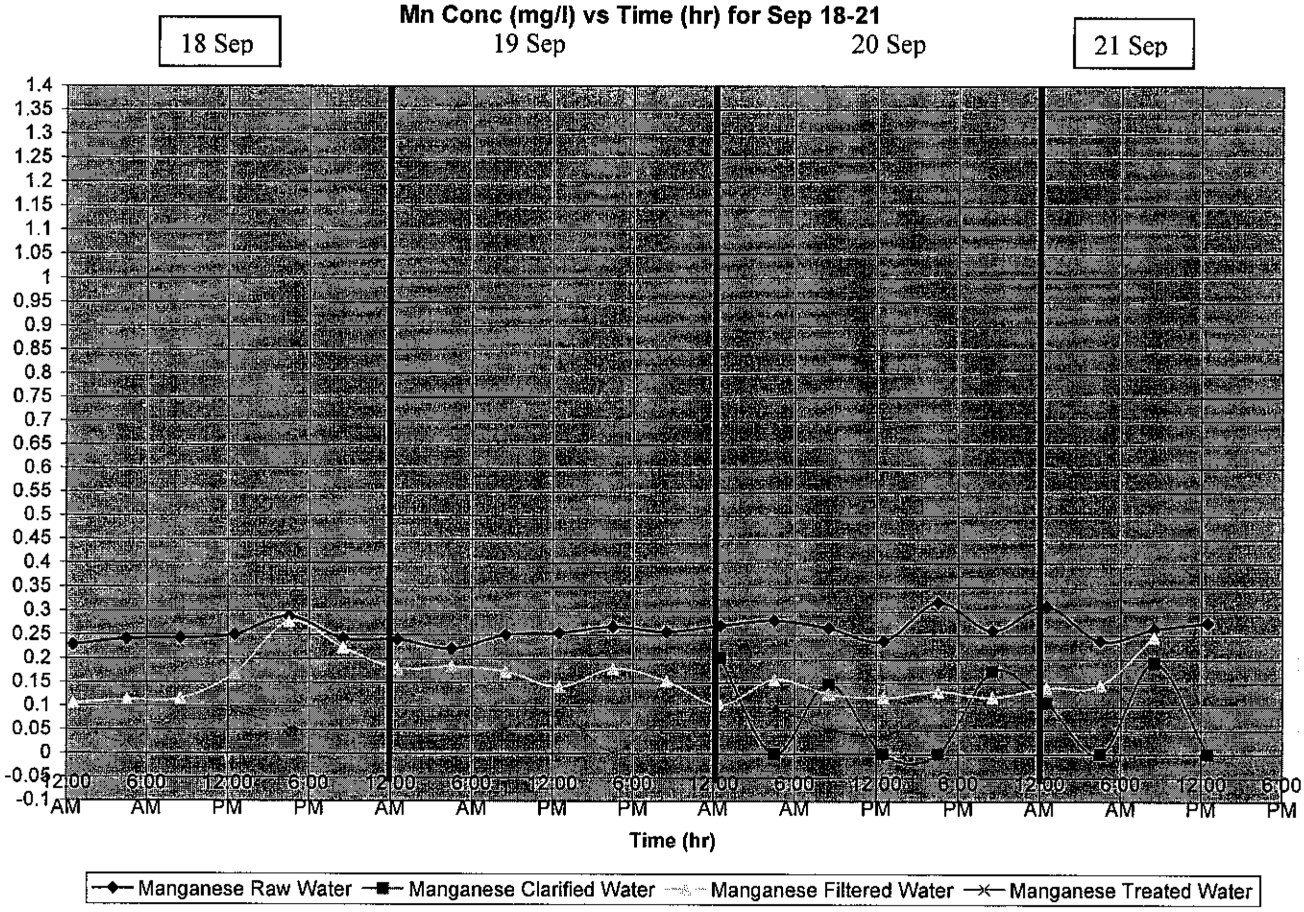

Figure 2-21: Mn Conc (mg/l) vs Time (hr) for Sep 18-21

Once again, the readings are quite high. It is no surprise that raw water reading would be the highest among all the other readings. The main concern is once again the treated water reading which is a bit higher than 0.05 mg/l. Only in some periods it is below 0.05 mg/l but not substantially. Maintenance cleaning should be done throughout the whole process more frequently to eradicate this problem. Addition of chemicals should be monitored and maintained at the stable rate.

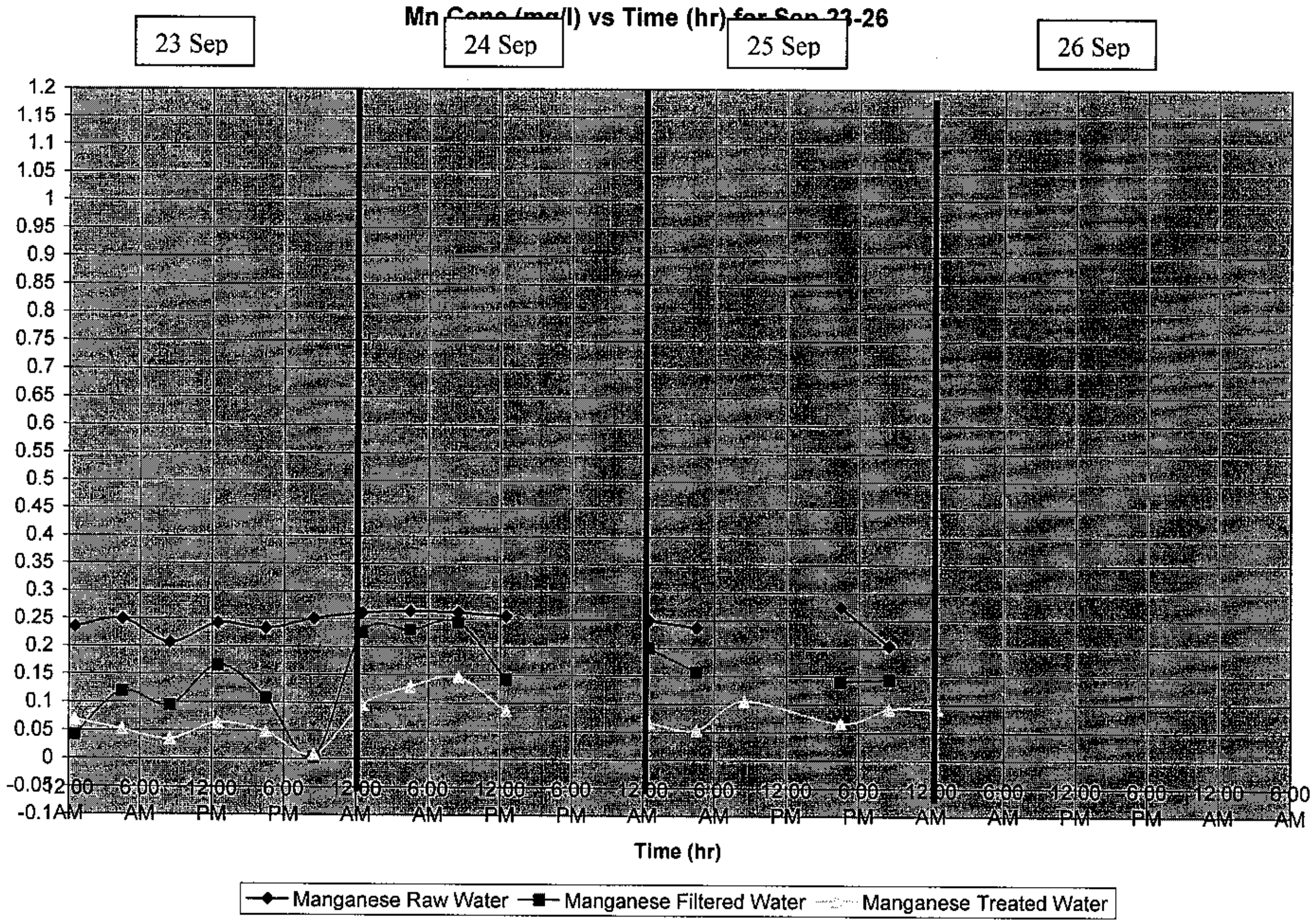

Figure 2-22: Mn Conc (mg/l) vs Time (hr) for Sep 23-26

Same old problems occur in these readings. Treated manganese water readings are above the standard of 0.05 mg/l. Same appropriate actions should be taken which were discussed earlier. This is a big blow for the plant performance to abide all the regulations and the rules. It should be dealt as soon as possible.

5th Graph Sequence: Inflow

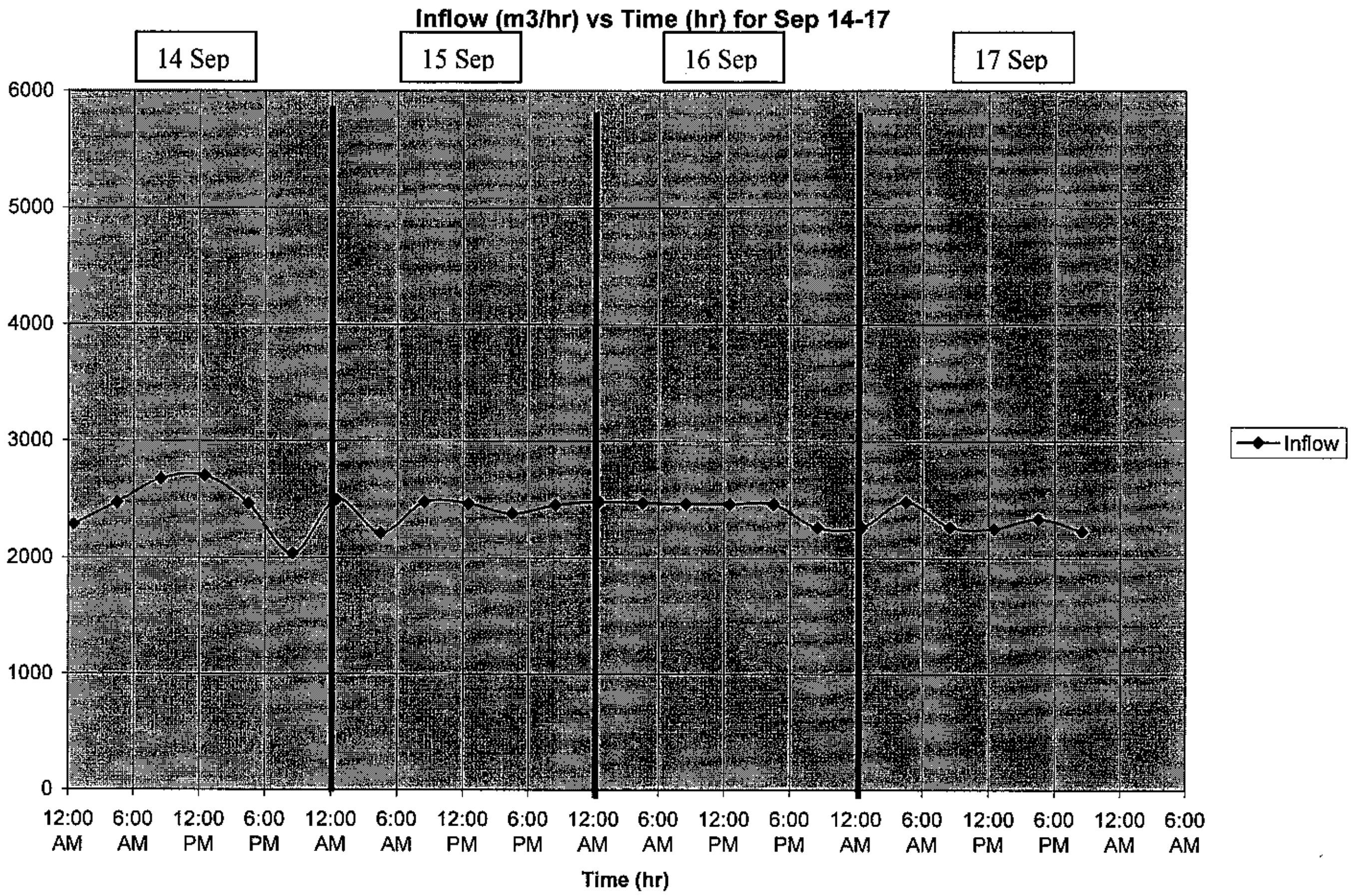

Figure 2-23: Inflow (m3/hr) vs Time (hr) for Sep 14-17

Inflow is used in evaluating treatment plant capacity. If the inflow is too low it would be difficult to perform efficiently for the plant. As shown above, the inflow reading range is in between 2000 and 3000 m3/hr, It is quite acceptable considering the flow is coming from the ground. The plant should perform efficiently under these conditions.

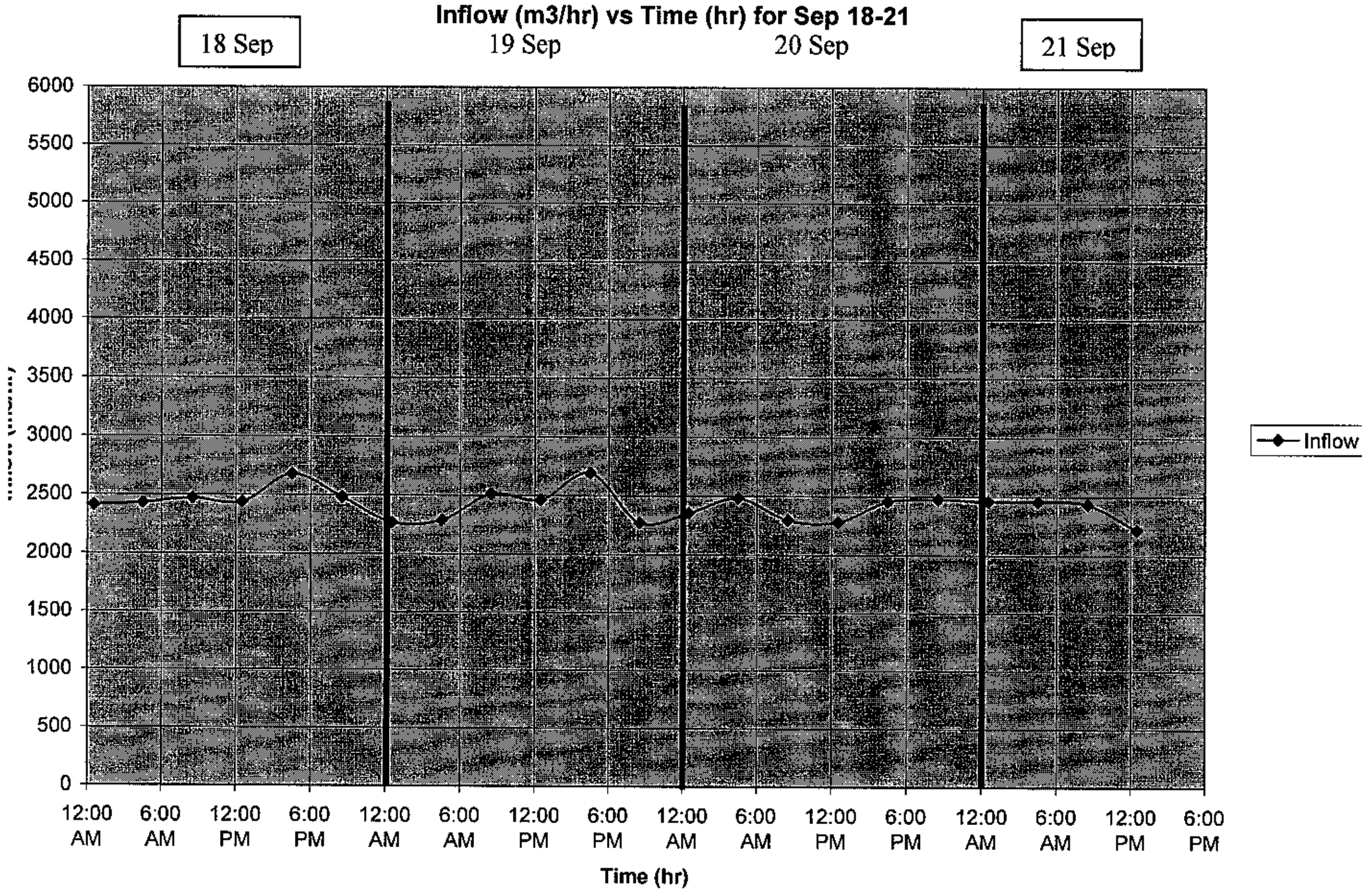

Figure 2-24: Inflow (m3/hr) vs Time (hr) for Sep 18-21

Once again, the readings are quite good to evaluate the performance. It's in the region of 2500 m3/hr which is a positive result. From the readings it is obvious that treatment plant tried to maintain the stable rate. The plant should perform well under these conditions.

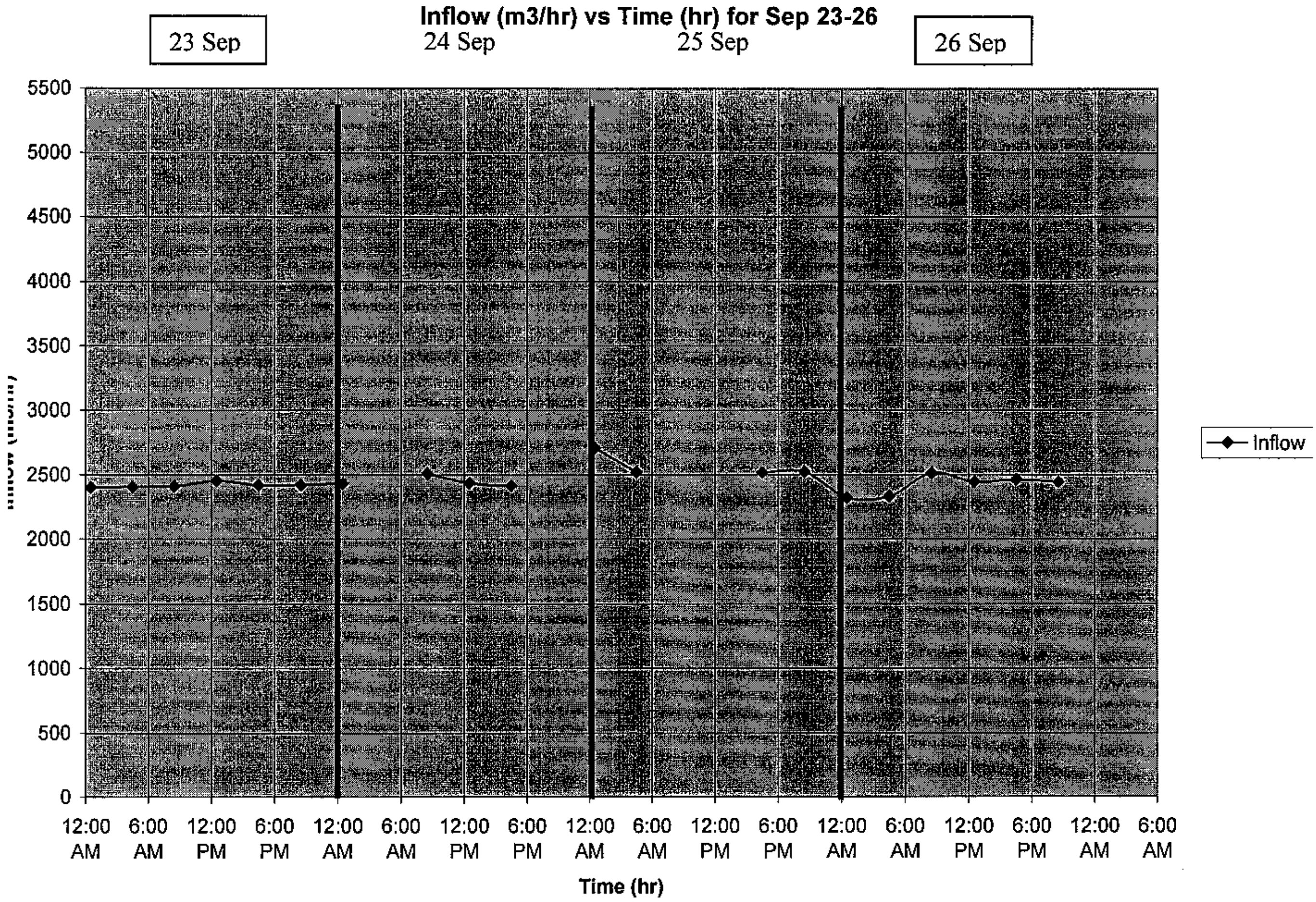

Figure 2-25: Inflow (m3/hr) vs Time (hr) for Sep 23-26

Some of data isn't available in this graph. However, it is enough to conclude that inflow rate is in the region of 2500 m3/hr approximately. It is good for performance of the plant in terms of design capacity it can take. It should provide many areas with water at a stable a rate.

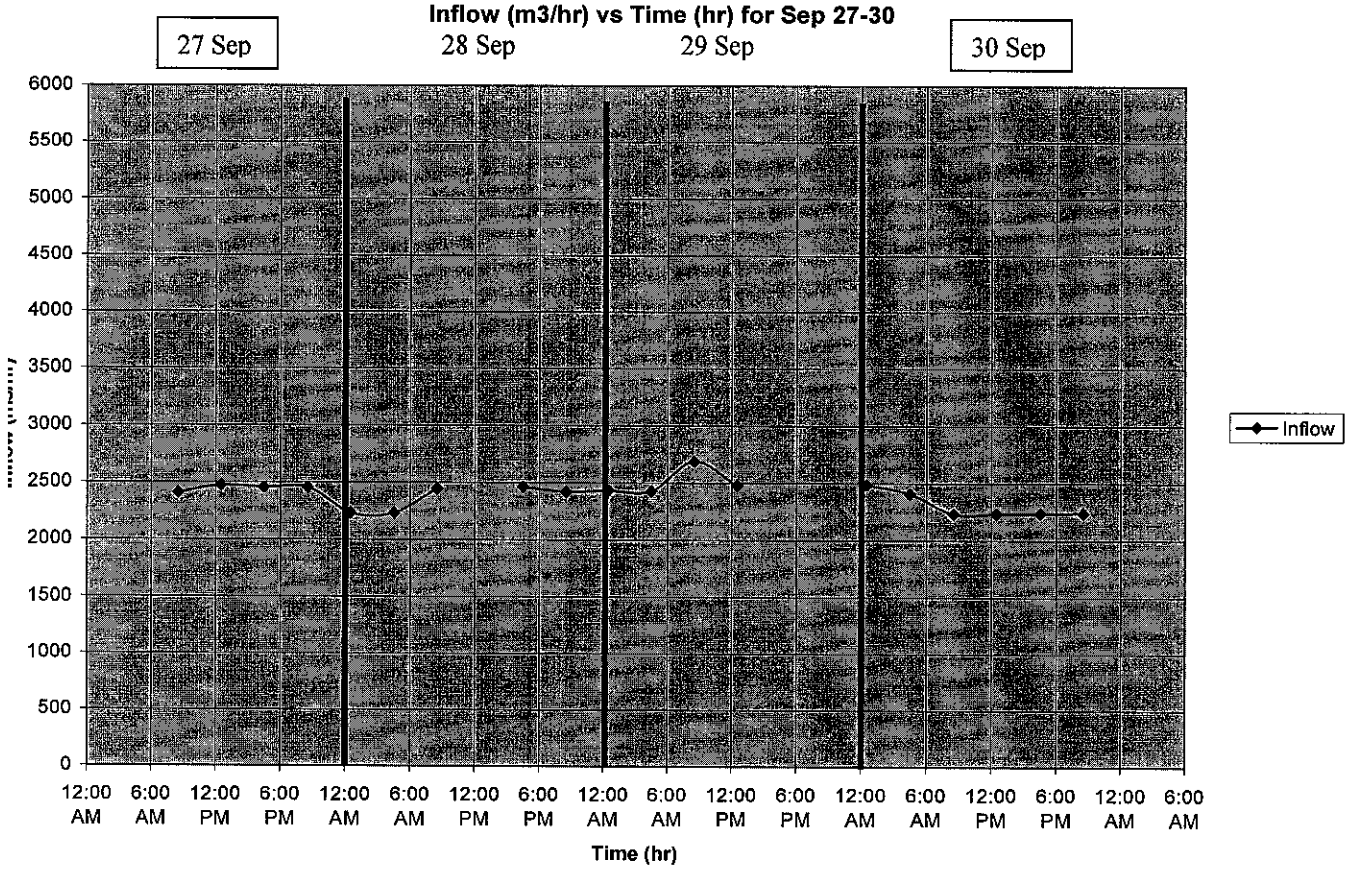

Figure 2-26: Inflow (m3/hr) vs Time (hr) for Sep 27-30

Once again, the inflow readings are in the region of 2500 m3/hr. It is an efficient performance for the plant to maintain the stable rate of 2500 m3/hr. However some data is missing to make any concrete conclusions. The conditions are acceptable for the treatment plant capacity.

2.2.7 Experimental Data Analysis on Chicha Water for 19th March, 2005

The experiment was conducted by Hj Hasani, an engineer at Chicha Water plant. He recommended the usage of sodium hypochlorite as a disinfectant. Usually calcium hypochlorite is used, but sodium hypochlorite may be used in the absence of calcium hypochlorite. This chemical is available only in liquid form in strengths up to 12-15% available chlorine. This means for every 1 litre used, 0.12 to 0.15 litres of chlorine is available for disinfection, the rest is water. The unstable nature of sodium hypochlorite solutions may result in the labeled chlorine concentration not being available for disinfection at the time of use. A common form of sodium hypochlorite is household laundry bleach that has, at best, approximately 5% available chlorine.

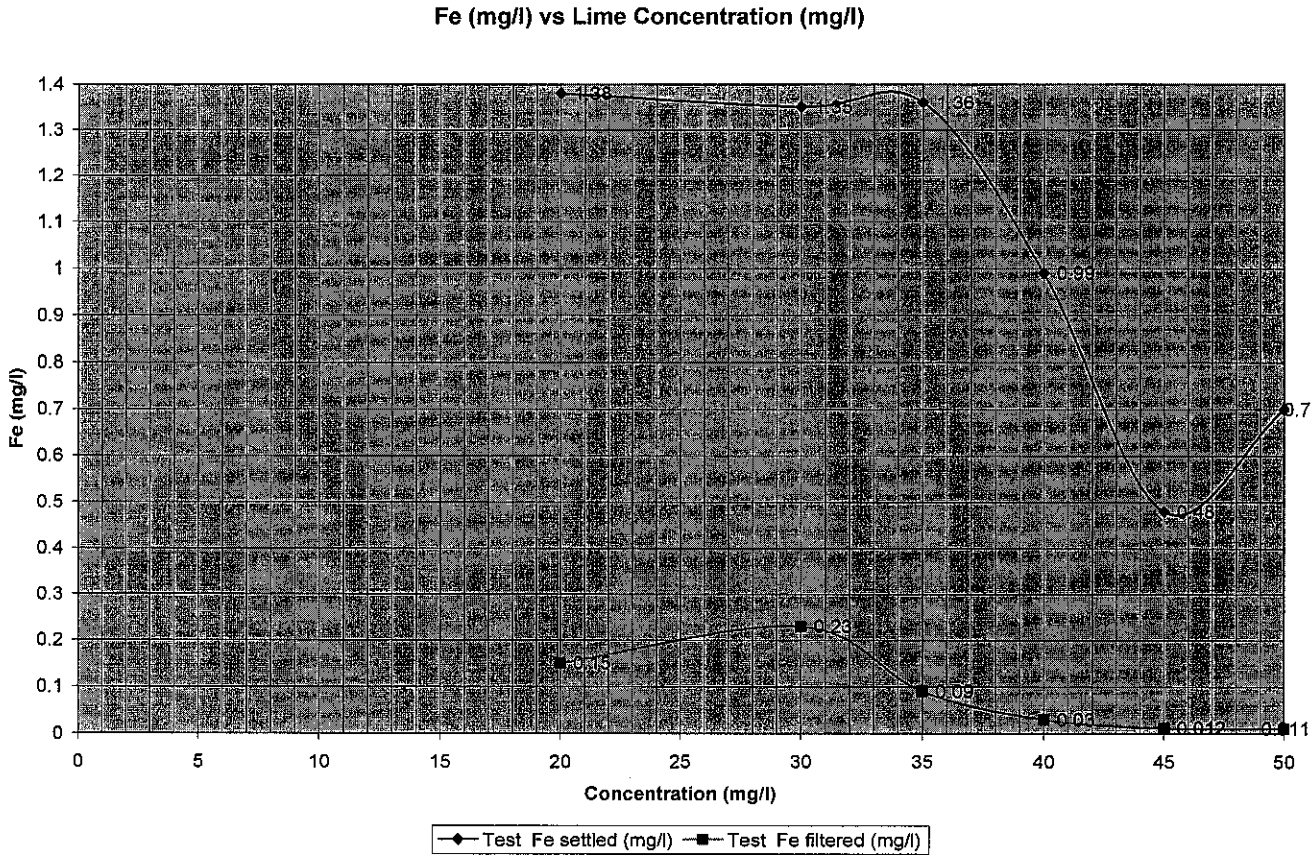

Figure 2-27: Fe (mg/l) vs Lime Concentration (mg/l)

Fe concentrations as shown above vary with every added chemical concentration. Fe settled water readings are not quite accurate; especially the final reading when there is a substantial increase. However, the final reading is still below WHO standard which is 0.3 mg/l. Fe filtered water readings are relatively low, as low as 0.011mg/l which is the final reading. This is a very positive result that also proves chemical additions of sodium hypochlorite, alum effectively reduce the Fe concentrations.

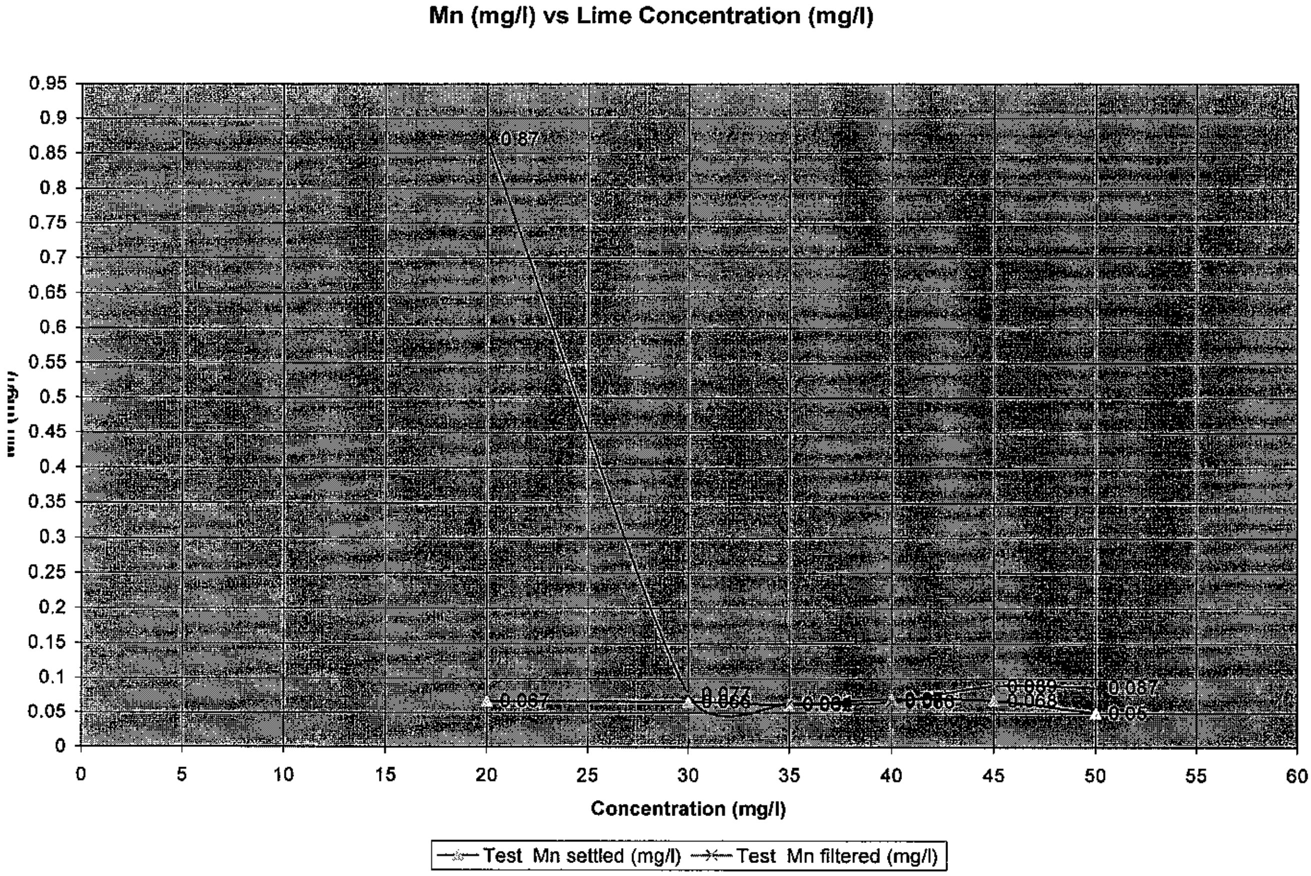

Figure 2-28: Mn (mg/l) vs Lime Concentration (mg/l)

As shown above, Mn concentration for settled and filtered water decreases. The chemical additions such as sodium hyper chloride, lime effectively decrease the Mn concentrations. There is a sudden drop in Mn filtered water reading, and a slight increase towards the end. Engineer Hj. Hasani commented that Mn concentration decrease was achieved with some difficulties. Chicha plant faces major obstacles in removal of Mn concentration rather than Fe. Mn settled water readings are quite constant, with a slight decrease.

Chapter 3

3.0 Methodology

3.1 Experiment Procedures

Brief overview of the conducted tests: As shown below, five main procedures have to be followed. Each of them is discussed in detail.

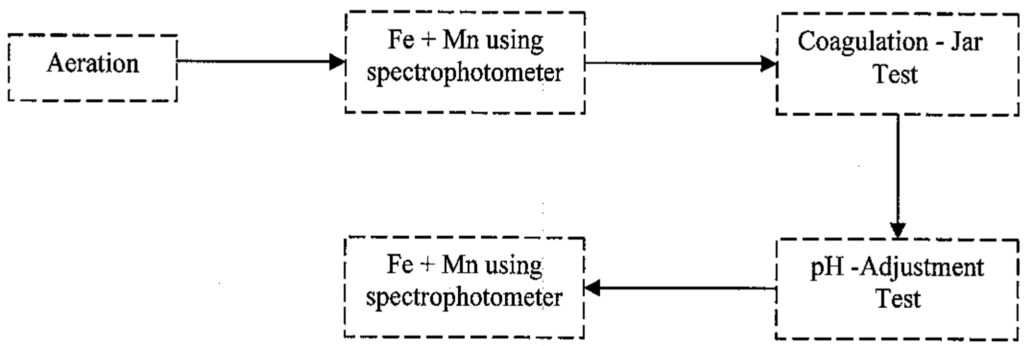

Figure 3-1: Experimental Process Flow Chart

3.1.1 Aeration

This is a preliminary test before determination of the concentration of the iron and manganese. Aeration unit is used to aerate the water samples of total amount of 20 liters which was taken from Chicha plant. The water sample taken is raw water which could have the maximum concentration of iron and manganese. Every hour a 100 ml of water is taken from aeration unit to determine the concentrations of iron and manganese. This procedure continues until the results for concentrations of iron and manganese become stable. Lime can be added prior to aeration for more effective removal of iron and manganese. Also the important aspect is fine bubbles throughout the aeration.

3.1.2 Determination of Fe and Mn using spectrophotometer

This test is followed after aeration test. There are 2 methods to determine Fe and Mn respectively both of them using powder pillows. Spectrophotometer is used to determine the concentrations of Fe and Mn. To proceed to spectrophotometer step, water samples taken from aeration unit are filtered using filter paper. The next steps are as follows:

Figure 3-2: Type of a Spectrophotometer

Determination of Fe concentration: Method 8008 from water analysis handbook or in other words FerroVer Method is used. The three 10 ml sample cells are filled with the water from aeration unit. FerroVer iron reagent powder pillow is added to each sample cell and swirled to mix. Another blank sample (water sample from aeration unit) is prepared. On the spectrophotometer, 3 minute reaction period begins. Upon period ending, blank sample is placed into cell holder in spectrophotometer to zero the Fe concentration. Afterwards, the Fe concentrations of all three samples are measured. The average value is considered among the three results. In handling the experiment, a great care should be given to maintaining the cleanliness of all apparatus used. Any slight change to maintain the apparatus might affect the results obtained. The results obtained are in mg/l units.

Determination of Mn concentration: Method 8149 from water analysis handbook or in other words Naphthol Pan Method LR is used. The three 10 ml sample cells are filled with the water from aeration unit. Another 10 ml blank sample (deonized water) is prepared. Ascorbic acid powder pillow is added to each sample cell and inverted to mix. 15 drops of Alkaline-Cyanide reagent solution is added followed by 21 drops of PAN Indicator solution 0.1 % to each sample cell. All samples are inverted gently to mix. On the spectrophotometer, 2 minute reaction period begins. Upon period ending, blank sample is placed into cell holder in spectrophotometer to zero the Mn concentration. Afterwards, the Mn concentrations of all three samples are measured. The average value is considered among the three results. It is very important that the reagent solutions used are handled properly and carefully due to acidity of the chemical which can cause death at any moment. Also in handling the experiment, a great care should be given to maintaining the cleanliness of all apparatus used. Any slight change to maintain the apparatus might affect the results obtained. The results obtained are in mg/l units.

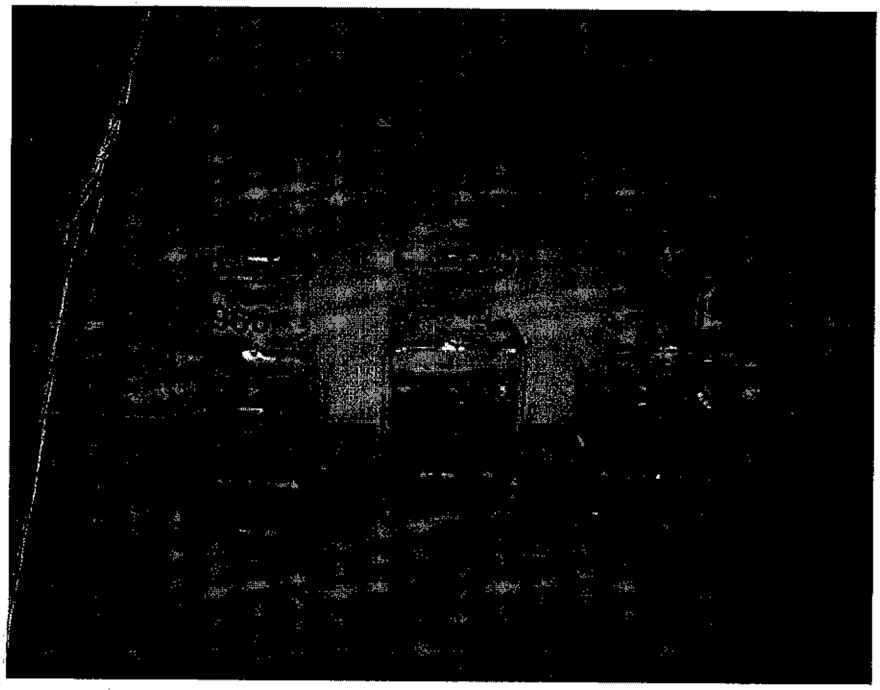

Figure 3-3: Colour (Orange) Change after addition of Pan Indicator Solution 0.1 %

Figure 3-4: Colour (Yellow) Change after mixing

3.1.3 Coagulation-Jar Test

Coagulation is a process of destabilizing colloidal particles so that practical growth can occur during flocculation. Colloidal particles normally have a net negative surface charge. The attractive forces between colloidal particles are considerably less than repelling forces of the electrical charge due to its small size. As particles grow, gravity sedimentation, filtration and other inexpensive particle separation procedures become feasible. The pertinent reaction for alum is

$$Al_2(SO_4)_3 . 18H_20 + 3Ca(H_2O)_2 \rightarrow 3CaSO_4 + 2Al(OH)_3 + 6CO_2 + 18H_2O$$

Commonly used metal coagulants in water treatment are (1) those based on aluminium, such as aluminium sulphate, sodium aluminate, potash alum and ammonia alum; and (2) those based on iron, such as ferric sulphate, ferrous sulphate, chlorinated ferrous sulphate and ferric chloride. The description that follows gives some of the relevant properties and chemical reactions of these substances in the coagulation of water. Studies have shown that the hydrolysis of iron and aluminium salts is far more complicated than these formulas would indicate; however, they are useful in approximating the reaction products and quantitative relationships.

Aluminium sulphate, $Al_2(SO_4)_3 \cdot 14.3H_2O$, is by far the most widely used coagulant; the commercial product is commonly known as alum, filter alum or alumina sulphate. Filter alum is a grayish-white crystallized solid containing approximately 17 percent water soluble Al_2O_3 and is available in lump, ground or powdered forms as well as concentrated solution. Ground alum is commonly measured by a gravimetric-type feeder into a solution tank from which it is transmitted to the point of application by pumping. Amber-coloured liquid aluminium sulphate contains about 8 percent available Al_2O_3.

Jar Test: This test is followed after determination of Fe and Mn concentrations using spectrophotometer. Jar testing provides a method of determining the best coagulant, operating pH and dosage for a given water or waste water. It is also intended to simulate the coagulation/flocculation process in a water treatment plant. The results that it produces are used to help optimize the performance of the plant. The pH of several water samples is adjusted to pre-selected values. Slow mixing is needed for coagulation reactions and initial aggregation to occur. This is where the particles grow through flocculation process. The paddle of the stirrer has a variable speed operation between 0 to 190 rpm. Procedures are as follows:

Six 1000 ml samples are filled with the aerated water. Either 10 % or 8 % concentration of alum is added as a coagulant into each jar at different amounts (vary with each other). At the same time all samples are mixed at high speed of 185 rpm for 5 minutes. Afterwards it is followed by 25 rpm (minimum) for about 10 minutes. Once stirrer stops, the floc in the samples is allowed to settle for 30 minutes. Ph is measured for each sample followed by determination of Fe and Mn using spectrophotometer. The procedures are the same for determination of Fe and Mn concentrations which were described earlier.

3.1.4 pH Adjustment test

pH is the concentration of hydrogen ion (H^+) in water it is commonly expressed in logarithmic scale. It indicates the acidity or alkalinity of solution. In neutral pH water at 25°C has hydrogen ion concentration of 1×10^{-7} M. The pH is equal to 7. The pH for acid solution should be less than 7 and for base solution the pH should be higher than 7. In this test, electrodes of the water quality multiprobe are used to determine the pH readings.

Acidity is usually attributed to water samples with pH readings below the value of 7.00. In unpolluted water, acidity comes from dissolved CO_2 or organic acid leached from the soil. Atmospheric pollution can also attribute to acidity. Acidic water may cause great harm to human as well as buildings. Metal or concrete of a building may be corroded as an effect of this. The acidity of water is determined by titrating a water sample with 0.02N NaOH.

Alkalinity is a measure of the buffering capacity of water. Alkalinity is caused primarily by chemical compounds dissolved from the rocks and soil and is mainly due to the presence of hydroxyl (OH^-), carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions. These compounds are mostly the carbonates and bicarbonates of sodium (Na), potassium (K), magnesium (Mg) and calcium (Ca). Other ions that may contribute to alkalinity but are generally found at low concentrations are $H_2PO_4^-$, HPO_4^-, PO_4^{3-}, HSO_3^-, $H_2BO_3^-$, HS^-. Alkalinity in water is determined by titrating a sample of water with 0.02N HCl solution

Chapter 4

4.0 Results and Discussion

The mentioned experiments were carried out in UTP and the Chicha plant lab. All these results are summarized in the tables and are attached in Appendix.
Some of the results are not accurate due to equipment maintenance. For the trial & error experiments the water which was taken from Chicha plant has aerated itself inside the tank before the experiment, thus causing some inaccurate results. However it is clearly seen that Fe and Mn concentrations are quite low than expected. Also in the latter experiments alum and lime were used to further reduce the concentrations of iron and manganese. Hypo was used in last experiment. Obtained results were sufficient enough to come up with conclusions but controversial results were also present. For example,
For the table in Appendix B which is trial-error table, the Fe concentrations are quite low for first 2-3 hours of aerating. In latter stages of aeration, results show inconsistency. For Mn concentrations, the results are not that accurate. There was a big problem in pH measurement. The equipment used to measure pH was not giving any stable, consistent results. It was difficult to determine the pH for the main reason was that alkalinity of the water. Alkalinity as mentioned before is a measure of the buffering capacity of water. In other words, it is the capacity of a solution to neutralize added acid down to a specified pH value, which for most natural waters is a pH of 4.5-4.8. For Chicha lab results, the iron concentration was increasing in the 1st test rather than the decrease as it is supposed to be. All the readings were taken only once (single cell measurement only) due to time constraint rather than three times, therefore the results are more inaccurate. Also in the 2nd test, the readings decrease in the beginning, but in latter stages it increases.

UTP Tests:

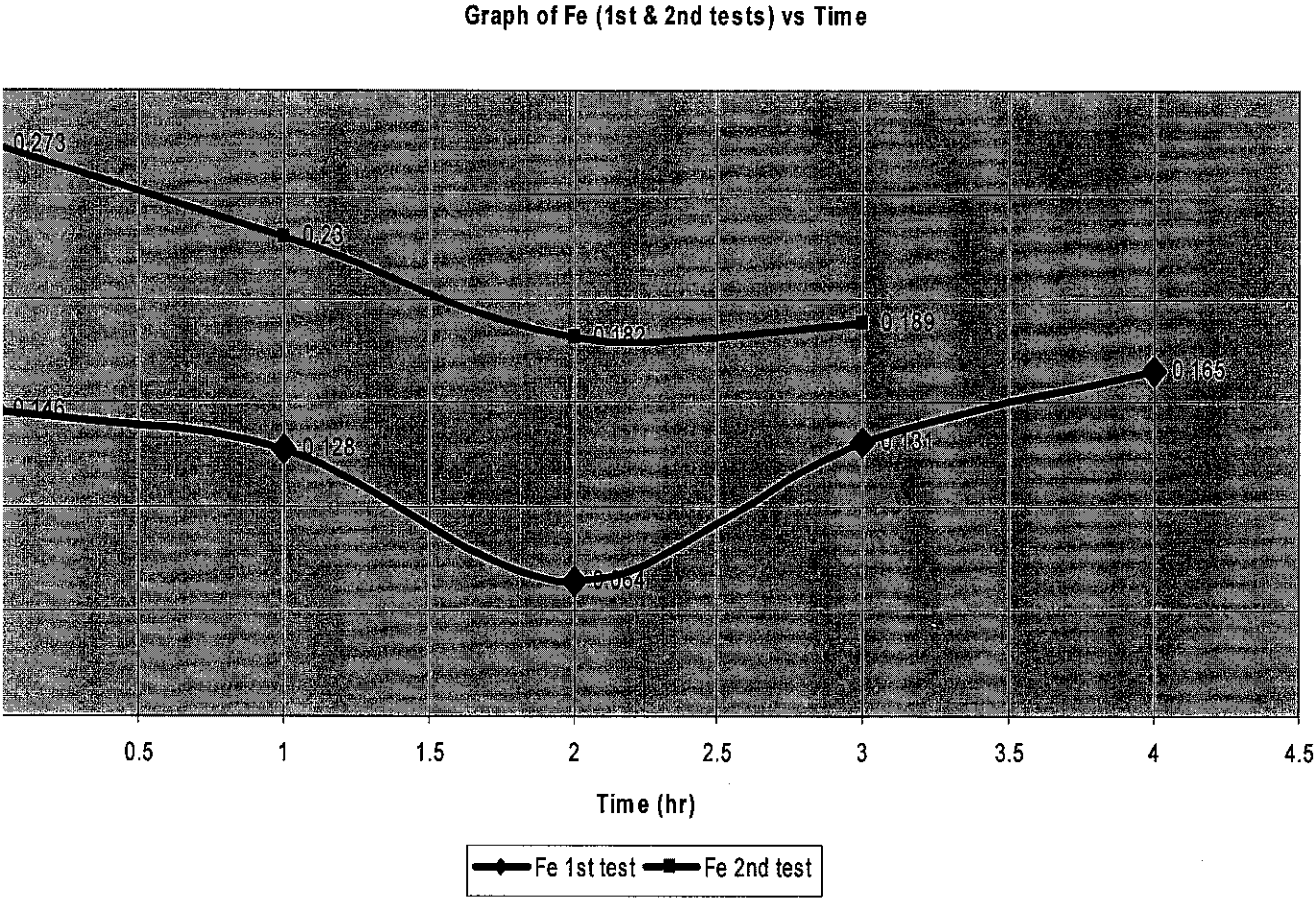

Figure 4-1: Graph of Fe (1st & 2nd) tests vs. Time

This graph was obtained from the results after aeration test before the coagulation stage. The 1st test results are lower than of the 2nd test. The main reason is that the sample for the 1st test was not properly handled. The water got aerated itself before the aeration thus the Fe concentration would decrease drastically. For the 2nd test, results are much better due to that experiment was done without any delays. The results are low as predicted; however aeration would not incur much decrease, it has to be followed by another removal process.

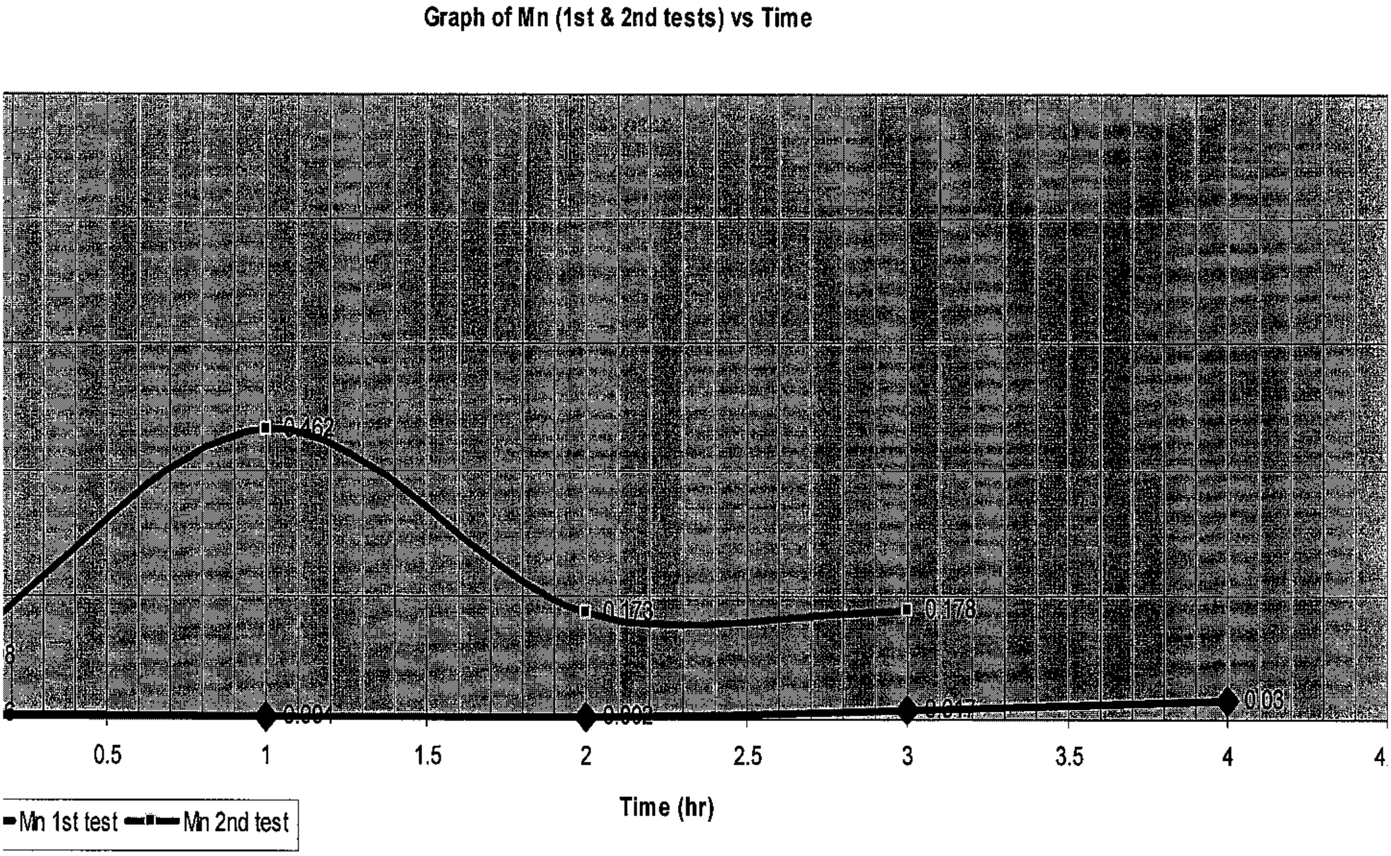

Figure 4-2: Graph of Mn (1st & 2nd) tests vs. Time

As shown in the graph, the results vary with other. The 1st test results are lower because sample was not in a good condition. As for the 2nd test, the results are quite high, above the WHO standard 0.05 mg/l. Note that sample was in good condition, and obtained results indicate that aeration does not decrease Mn concentrations that much. No chemicals were added throughout the process, and it would be followed by coagulation process with alum as an active coagulant

Combined Graph of Fe 1st & 2nd tests

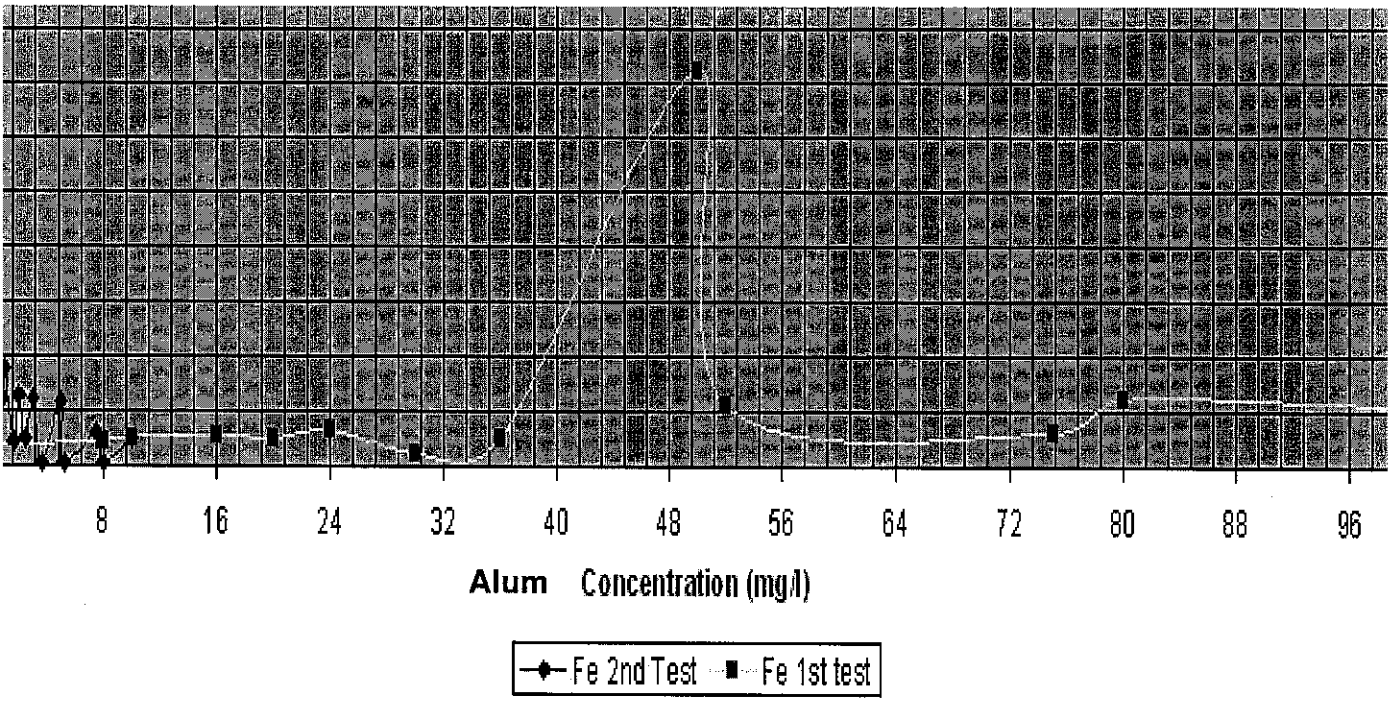

Figure 4-3: Combined Graph of Fe (1st & 2nd) tests vs. Alum concentration

These results were obtained after a jar test experiment. In other words, follow up to aeration process namely coagulation. For the 2nd test which was between 0-10 mg/l concentrations, the results seem to be linear with some small jumps. The results for the 1st are also quite good except the big jump. Notice that both test results are lower than Fe standard set WHO which is 0.3 mg/l. The methods used such as aeration and coagulation proved to be efficient with usage of alum, however there was no chemical addition of lime.

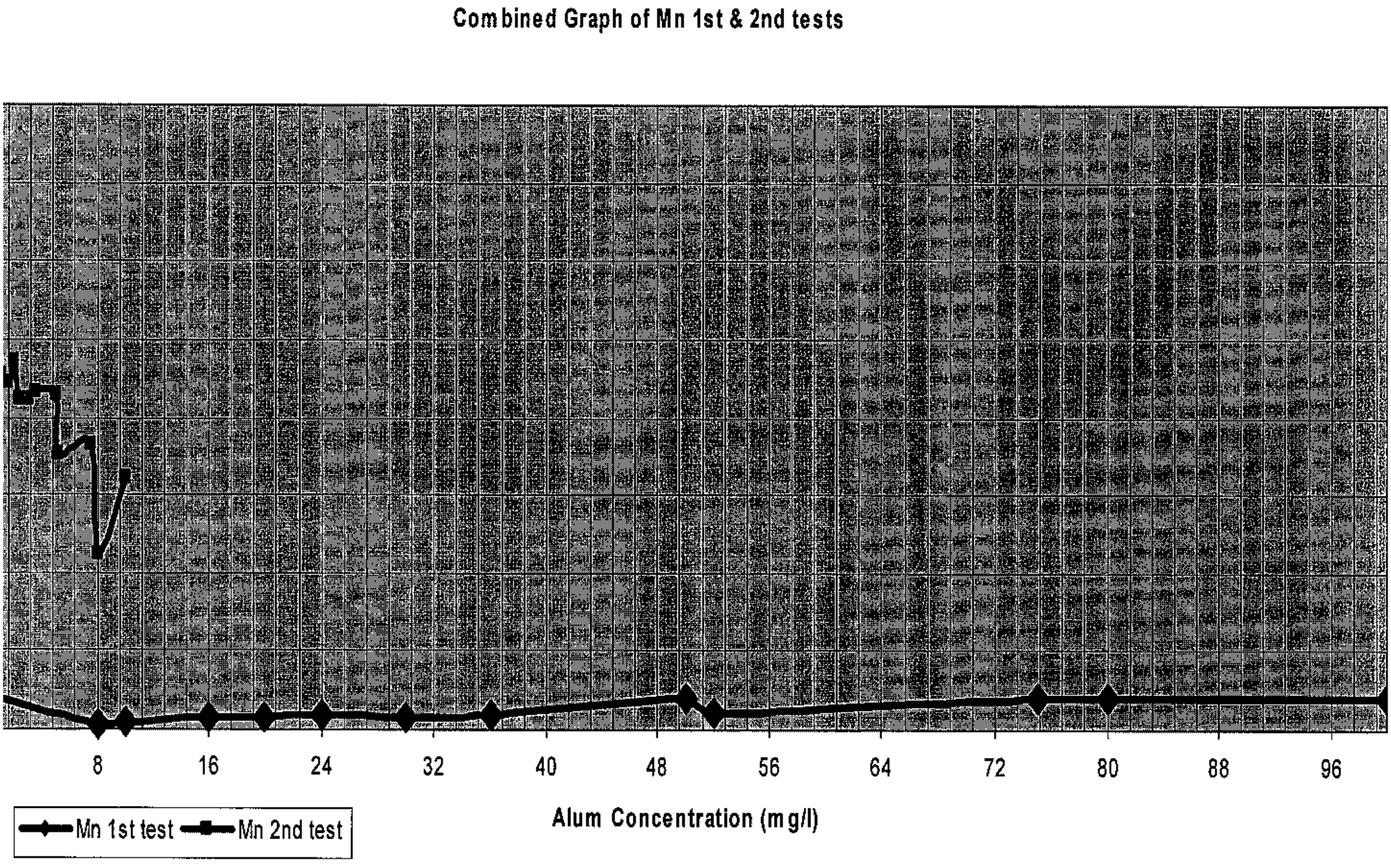

Figure 4-4: Combined Graph of Mn (1st & 2nd) tests vs. Alum concentration

Once again, the 1st test results are lower than 2nd test. It may be due to that sample got aerated itself before the experiment. Alum was added as a coagulant; however the results of 2nd test are above the WHO standard 0.05 mg/l. This indicates that coagulation should be followed by another process with other chemical additions to tackle the Mn concentrations. Alum used might not be an effective chemical to reduce Mn %, other chemicals such as sodium hypochlorite might be recommended

Combined Graph Fe (Test 1 & 2) mg/l vs Alum Concentration

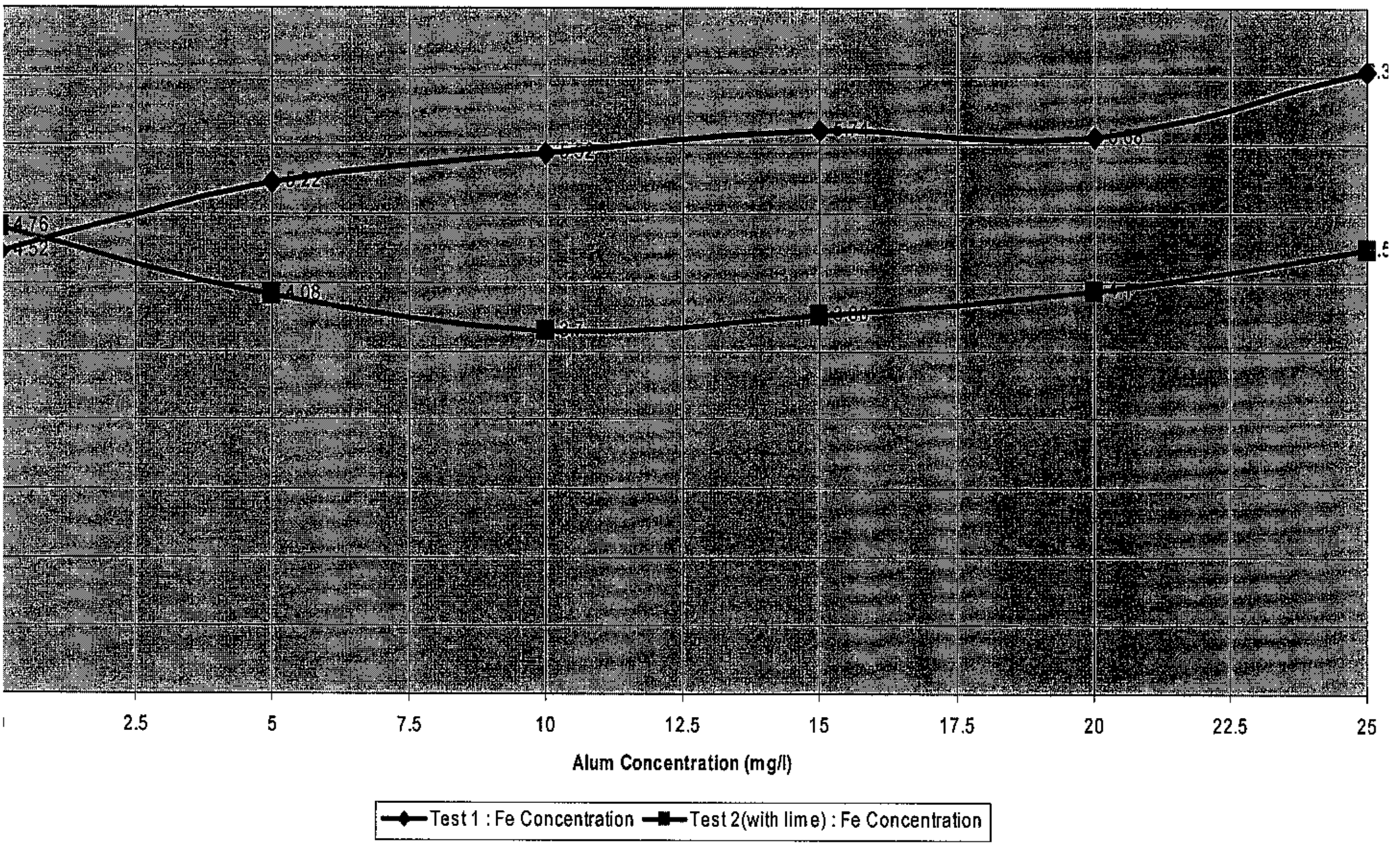

Figure 4-5: Combined Graph of Fe (1st & 2nd) tests vs. Alum concentration

Experiments conducted at the Chicha plant lab yielded some unexpected results. Alum was added in the 1st test, but for the 2nd test lime plus alum were added. As shown in the graph, the readings tend to vary with every added concentration of alum. The final readings are above WHO standard of 0.3 mg/l, thus these results are unacceptable. Fe concentration for test 2 is quite odd; there is a decrease in the beginning but again it increases towards the end. After careful observation of these readings, official from Chicha water plant refused to comment. Both of these test results were obtained using jar test using raw water sample without aeration.

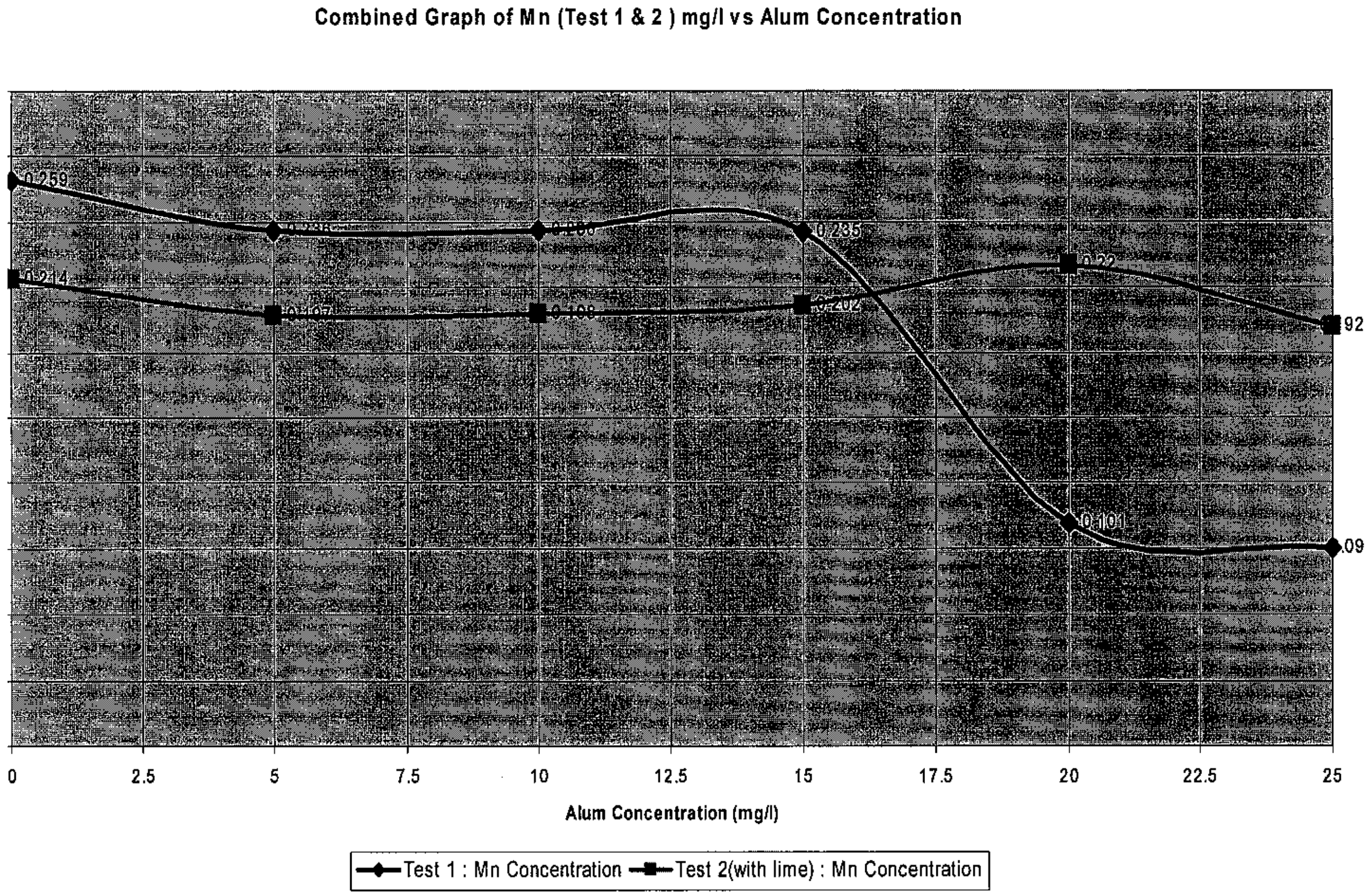

Figure 4-6: Combined Graph of Mn (1st & 2nd) tests vs. Alum concentration

The results of Mn concentrations for each test vary with each other. Test 1 Mn concentration readings are constant except the final readings when there is sudden drop. However, it is still above WHO standard which is 0.05 mg/l. As for Mn concentration of test 2, the readings are quite high. Even though there is a slight decrease in the final reading, it is still above WHO standard. Both lime & alum were added in the 2nd test, while only alum was added in the 1st. The 2nd test readings indicate that while the results are high, lime might have caused the delay in decrease of Mn concentration. Both of these test results were obtained using jar test using raw water sample without aeration.

UTP Tests (cont'd):

Fe (mg/l) & Mn (mg/l) concentrations vs Time (hr)

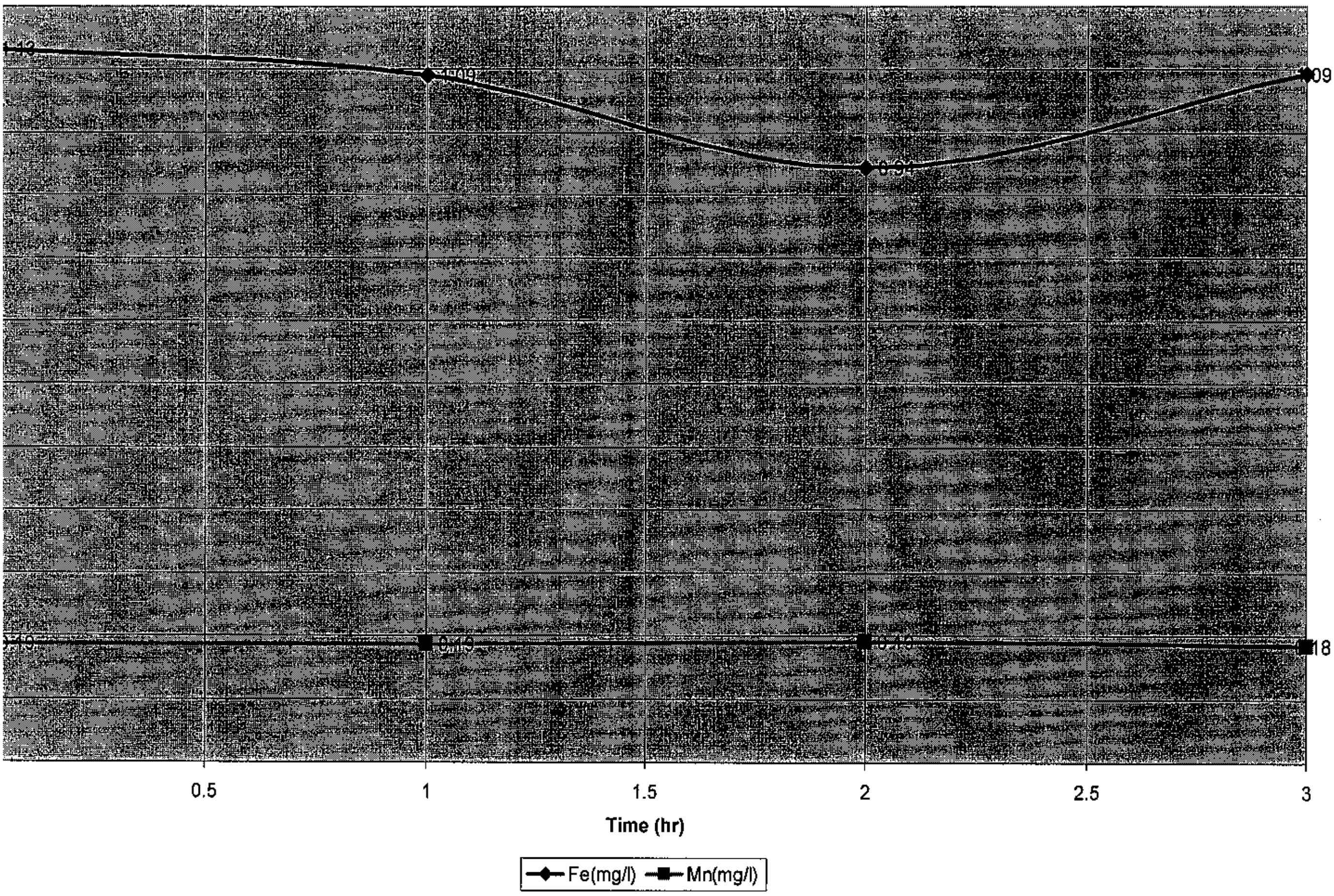

Figure 4-7: Combined Graph of Fe & Mn (1st UTP) test vs. Time (hr)

This graph was obtained from the results after aeration test before the coagulation stage. Fe concentrations vary with each other; on the other hand Mn concentrations are constant. Even though both of the results are above WHO standards, it still proves that aeration is not effective enough to reduce the concentrations. Note that aeration has to be followed by another removal process with some chemical additions, which would incur some more decrease in the Fe & Mn concentrations respectively

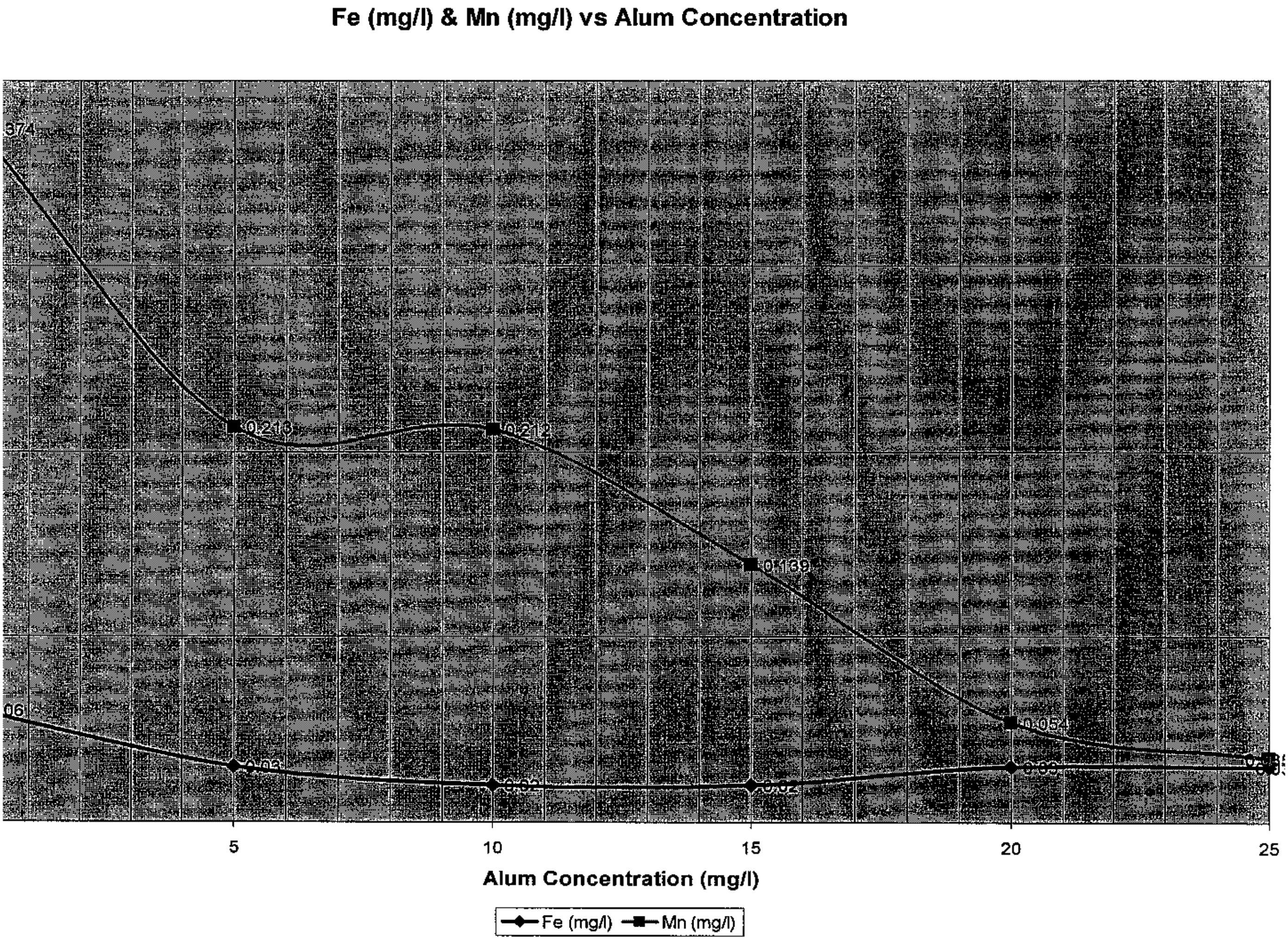

Figure 4-8: Combined Graph of Fe & Mn (1st UTP) test vs. Alum concentration

Fe concentrations are very low, as low as 0.02 mg/l as shown above. Another point is that in aeration process, the results were very high, followed by alum addition which was very effective in reducing the concentrations of Fe and Mn. The first reading of Fe starts at 0.06 mg/l, and in previous experiment it ended at 1.09 mg/l. The Fe concentration has very much decreased and yielded very much decreased readings. As for Mn, the results are very good, with sharp decrease with every added alum concentration. Mn concentrations are as low as 0.035 mg/l, which is below the WHO standard 0.05 mg/l. Thus usage of alum in coagulation stage proves to be very efficient

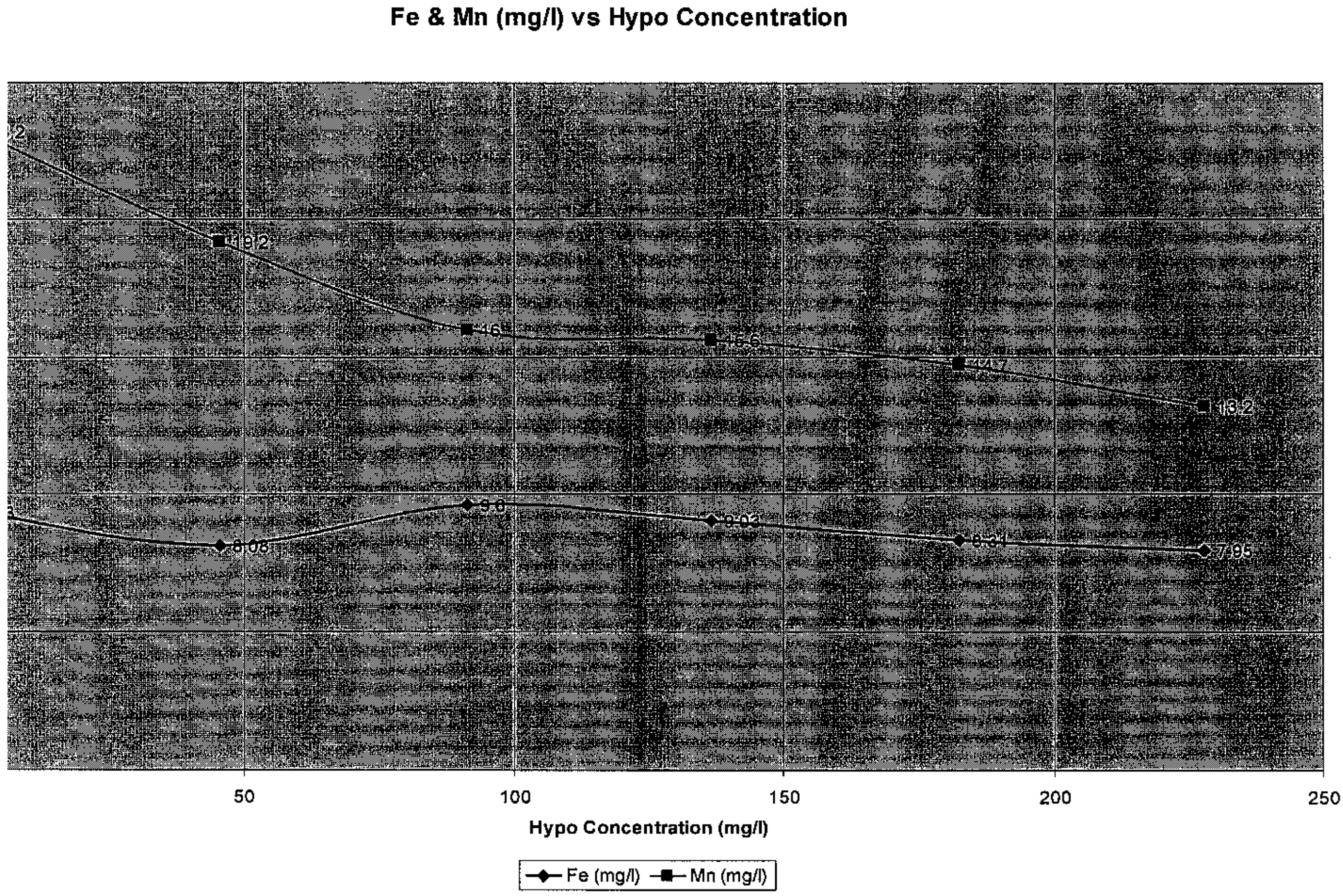

Figure 4-9: Combined Graph of Fe & Mn (2nd UTP) test vs. Hypo concentration

This was a final experiment with the usage of sodium hypochlorite. Iron and Manganese solution were added to the sample water to obtain initial high readings of Fe & Mn and also to check the effectiveness of hypo. As shown in the graph, Mn concentrations decrease with every added hypo concentration. Thus, it proves to be very effective to remove Mn concentrations. As for Fe concentration, the readings vary with each other. It might be due to iron solution added prior to experiment stipulated such uncertainty. However, hypo might be an ideal replacement for other chemical additions

Chapter 5

5.0 Conclusion & Recommendations

Aeration would not cause much decrease for Fe and Mn concentrations; it has to be followed by another removal process. Coagulation, flocculation after aeration further decreases the Fe and Mn concentrations in the water. These mentioned processes have to be followed after aeration in order to maintain or achieve the desired results set by WHO standards. Usage of chemicals is not recommended in aeration stage.

Alum proved to be very effective in coagulation stage, reducing Fe concentrations. As for Mn, sodium hypochlorite might be used. Experimental results show that alum is most consistent in terms of efficiency for iron removal methods. Concentrations of Fe are low as 0.02 mg/l and for Mn are 0.035 mg/l which is a tremendous result. Alum was the main chemical addition used in the experiments and most of the results are very positive with alum being used,

Lime causes the delay in decrease of Mn concentration in coagulation stage. Thus, usage of lime is not recommended at all. Chicha plant uses lime as main chemical addition in very large proportions, which is actually not that effective. Amount of chemicals which would be added should be monitored to avoid large concentrations, to approach with less chemical additions for the processes.

Sodium hypochlorite might be an ideal replacement for other chemical additions. After hypo addition, concentrations of Fe are 7.95 mg/l and Mn is 13.2 mg/l considering very high dosage of Fe & Mn solution. Effective to reduce both Fe & Mn concentrations. Cost is another factor which affects the selection of chemicals. Chicha plant use large amount of various chemicals at high cost, to cut the cost sodium hypochlorite is introduced. It is much cheaper than other chemicals such as lime, potassium permanganate, etc.

Chapter 6

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Chapter 7

APPENDICES

Appendix A*:* Technical Data on Chicha Water Treatment Plant from 14/09/04 - 30/09/04

Appendix B*:* Complete set of trial-error tables

a) Table of Fe and Mn Concentrations

Appendix C: Complete set of 2nd test results; tables

a) Table of Fe and Mn Concentrations

Appendix D*:* Complete set of tables of experiments conducted at the Chicha Water plant

Appendix E*:* Chicha Water experiment results conducted by Hj Hasani

Appendix F: Complete set of tables of experiments conducted in UTP (last experiments)

Appendix A

Date:14/09/2004			Time											
	Parameter	Unit	12:30 AM	2:30 AM	4:30 AM	6:30 AM	8:30 AM	10:30 AM	12:30 PM	2:30 PM	4:30 PM	6:30 PM	8:30 PM	10:30 PM
Raw Water	Inflow	m3/hr	2285		2473		2673		2700		2464		2035	
	pH		5.69		5.6		5.79		5.7		5.68		5.6	
	Turbidity	NTU	4.00		3.32		3.5		5.23		4.5		2.46	
	Iron	mg/l	-	n/a	-	n/a	-	n/a	-	n/a	5.88	n/a	5.89	n/a
	Manganese	mg/l	0.258	n/a	0.26	n/a	0.221	n/a	0.243	n/a	0.25	n/a	0.24	n/a
Mixing Water	pH		6.74		6.72		6.69		6.78		6.92		6.94	
Clarified Water	Turbidity	NTU	1.56		1.01		1.15		0.78		1.76		0.92	
	Iron	mg/l	n/a	n/a	n/a	n/a	-	n/a	n/a	n/a	n/a	n/a	4.11	n/a
	Manganese	mg/l	n/a	n/a	n/a	n/a	0.206	n/a	n/a	n/a	n/a	n/a	0.187	n/a
Filtered Water	Turbidity	NTU	0.22		0.06		0.1		0.08		0.13		0.08	
	Iron	mg/l	-	n/a	-	n/a	-	n/a	-	n/a	0.00	n/a		n/a
	Manganese	mg/l	0.167	n/a	0.17	n/a	0.166	n/a	0.159	n/a	0.127	n/a	0.121	n/a
Treated Water	pH		7.08		6.83		6.92		6.87		6.82		6.47	
	Turbidity	NTU	0.36		0.33		0.28		0.23		0.21		0.36	
	Colour	PtCo	0.35		0.16		0.14		0.00		0.21		0.00	
	Aluminium	µg/l	-105.5		-130.4		-		-101.8		-137.4		-138.1	
	Iron	mg/l	-	n/a	-	n/a	-	n/a	-	n/a	0.14	n/a	0.12	n/a
	Manganese	mg/l	0.08	n/a	0.12	n/a	0.092	n/a	0.068	n/a	0.01	n/a	0.087	n/a
	TFCR	mg/l	1.34		1.18		0.34		1.77		2.14		2.38	

Date:15/09/2004			Time											
	Parameter	Unit	12:30 AM	2:30 AM	4:30 AM	6:30 AM	8:30 AM	10:30 AM	12:30 PM	2:30 PM	4:30 PM	6:30 PM	8:30 PM	10:30 PM
Raw Water	Inflow	m3/hr	2496	2514	2214	2363	2477		2464		2380		2450	
	pH		5.61	5.69	5.64	5.66	5.65		5.61		5.6		5.63	
	Turbidity	NTU	2.43	8.36	8.93	8.94	9.24		7.52		7.42		3.53	
	Iron	mg/l	5.22	n/a	5.68	n/a	5.1	n/a	4.98	n/a	5.26	n/a	5.25	n/a
	Manganese	mg/l	0.292	n/a	0.229	n/a	0.249	n/a	0.253	n/a	0.27	n/a	-	n/a
Mixing Water	pH		6.81	7.33	6.63	6.92	6.88		6.94		7.09		6.77	
Clarified Water	Turbidity	NTU	0.872	1.239	1.229	1.173	1.082		1.098		1.158		1.043	
	Iron	mg/l	n/a	n/a	n/a	n/a	0.32	n/a	n/a	n/a	n/a	n/a	0.23	n/a
	Manganese	mg/l	n/a	n/a	n/a	n/a	0.192	n/a	n/a	n/a	n/a	n/a	-	n/a
Filtered Water	Turbidity	NTU	0.064	0.143	0.239	0.242	0.12		0.136		0.075		0.1	
	Iron	mg/l	0.01	n/a	0.11	n/a	0.00	n/a	0.19	n/a	0.09	n/a	0.03	n/a
	Manganese	mg/l	0.115	n/a	0.163	n/a	0.163	n/a	0.088	n/a	0.169	n/a	-	n/a
Treated Water	pH		7.01	7.38	7.06	7.14	7.02		6.95		6.73		8.76	
	Turbidity	NTU	0.333	0.454	0.408	0.403	0.428		0.376		0.349		0.24	
	Colour	PtCo	0.00	0.05	0.07	0.07	0.00		0.00		0.00		0.00	
	Aluminium	µg/l	-178.7	-199	-47.6	-40.00	61		35.9		13.2		31	
	Iron	mg/l	0.01	n/a	0.04	n/a	0.00	n/a	0.03	n/a	0.00	n/a	0.01	n/a
	Manganese	mg/l	0.072	n/a	0.076	n/a	0.087	n/a	0.07	n/a	0.078	n/a	0.086	n/a
	TFCR	mg/l	1.47	1.97	1.82	1.80	1.83		1.85		1.67		1.91	

Date:16/09/2004			Time											
	Parameter	Unit	12:30 AM	2:30 AM	4:30 AM	6:30 AM	8:30 AM	10:30 AM	12:30 PM	2:30 PM	4:30 PM	6:30 PM	8:30 PM	10:30 PM
Raw Water	Inflow	m3/hr	2480		2470		2460	2460	2460		2460		2259	
	pH		5.72		5.74		5.75	5.73	6.72		6.72		6.68	
	Turbidity	NTU	3.56		4.02		4.08	4.26	9.32		30.7		11.06	
	Iron	mg/l	4.91	n/a	5.16	n/a	5.97	n/a	5.84	n/a	5.64	n/a	5.34	n/a
	Manganese	mg/l	0.28	n/a	0.221	n/a	-	n/a	-	n/a	-	n/a	0.233	n/a
Mixing Water	pH		6.93		6.84		7.12	7.21	7.21		6.59		7.16	
Clarified Water	Turbidity	NTU	1.23		1.15		1.267	1.097	1.092		1.208		1.16	
	Iron	mg/l	n/a	n/a	n/a	n/a	0.66	n/a	n/a	n/a	n/a	n/a	0.19	n/a
	Manganese	mg/l	n/a	n/a	n/a	n/a	-	n/a	n/a	n/a	n/a	n/a	0.175	n/a
Filtered Water	Turbidity	NTU	0.18		0.11		0.101	0.096	0.094		0.148		0.14	
	Iron	mg/l	0.05	n/a	0.02	n/a	0.03	n/a	0.03	n/a	0.04	n/a	0.02	n/a
	Manganese	mg/l	0.146	n/a	0.118	n/a	-	n/a	-	n/a	-	n/a	0.068	n/a
Treated Water	pH		7.09		6.97		7.23	6.68	6.85		6.94		7.04	
	Turbidity	NTU	0.18		0.23		0.41	0.422	0.361		0.281		0.223	
	Colour	PtCo	0.00		0.00		0.00	0.00	0.00		0.00		0.00	
	Aluminium	µg/l	38.6		-54.6		-	-	-		-		-	
	Iron	mg/l	0.02	n/a	0.01	n/a	0.03	n/a	0.02	n/a	-0.03	n/a	0.01	n/a
	Manganese	mg/l	0.081	n/a	-	n/a	-	n/a	-	n/a	-	n/a	0.034	n/a
	TFCR	mg/l	1.4		0.98		1.11	0.97	1.04		1.03		0.26	

Date:17/09/2004			Time											
	Parameter	Unit	12:30 AM	2:30 AM	4:30 AM	6:30 AM	8:30 AM	10:30 AM	12:30 PM	2:30 PM	4:30 PM	6:30 PM	8:30 PM	10:30 PM
Raw Water	Inflow	m3/hr	2264		2480		2265			2253	2335	2264	2232	2342
	pH		6.65		6.73		6.63			6.63	6.65	6.66	6.67	6.64
	Turbidity	NTU	10.19		11.77		4.85			5.8	5.5	4.42	3.47	3.5
	Iron	mg/l	6.33	n/a	6.69	n/a	4.98	n/a		5.7	5.74	n/a	6.02	n/a
	Manganese	mg/l	0.228	n/a	0.261	n/a	0.227	n/a		0.248	0.243	n/a	0.239	n/a
Mixing Water	pH		7.32		6.99		7.4			7.15	7.45	7.31	7.32	7.29
Clarified Water	Turbidity	NTU	0.893		0.855		1.517			0.961	0.933	0.769	0.937	0.938
	Iron	mg/l	0.01	n/a	n/a	n/a	0.46	n/a	n/a	n/a	n/a	n/a	0.75	n/a
	Manganese	mg/l	n/a	n/a	n/a	n/a	0.16	n/a	n/a	n/a	n/a	n/a	0.15	n/a
Filtered Water	Turbidity	NTU	0.344		0.442		0.172			0.136	0.11	0.131	0.164	0.091
	Iron	mg/l	0.04	n/a	0.05	n/a	0.02	n/a		0.03	0.04	n/a	0.01	n/a
	Manganese	mg/l	0.051	n/a	0.136	n/a	0.073	n/a		0.136	0.136	n/a	0.095	n/a
Treated Water	pH		7.37		7.39		7.19			7.15	7.44	7.02	7.78	7.52
	Turbidity	NTU	0.13		0.086		0.598			0.384	0.418	0.429	0.34	0.322
	Colour	PtCo	0.00		0.00		0.00			0.00	0.00	0.03	0.02	0.00
	Aluminium	µg/l	-	-	-		-			-	-	-	-	-
	Iron	mg/l	0.03	n/a	0.03	n/a	0.01	n/a		0.01	0.04	n/a	0.02	n/a
	Manganese	mg/l	0.012	n/a	0.008	n/a	0.005	n/a		0.059	0.068	n/a	0.076	n/a
	TFCR	mg/l	0.43		0.45		0.32			1.45	1.69	2.14	2.13	1.99

)ate:18/09/2004

	Parameter	Unit	12:30 AM	2:30 AM	4:30 AM	6:30 AM	8:30 AM	10:30 AM	12:30 PM	2:30 PM	4:30 PM	6:30 PM	8:30 PM	10:30 PM
Raw Water	Inflow	m3/hr	2410		2430		2468	2624	2437	2463	2676		2482	
	pH		6.72		6.76		6.73	6.74	6.73	6.76	6.77		6.75	
	Turbidity	NTU	3.50		2.53		2.52	2.63	2.22	2.21	2.08		1.58	
	Iron	mg/l	5.94	n/a	5.26	n/a	5.4	n/a	5.71	n/a	6.66	n/a	5.89	n/a
	Manganese	mg/l	0.228	n/a	0.241	n/a	0.243	n/a	0.25	n/a	0.289	n/a	0.242	n/a
Mixing Water	pH		7.25		7.18		7.17	7.21	7.02	6.74	6.67		6.89	
Clarified Water	Turbidity	NTU	1.12		0.89		0.861	1.184	1.337	1.331	1.573		1.586	
	Iron	mg/l	n/a	n/a	n/a	n/a	0.45	n/a	n/a	n/a	n/a	n/a	0.75	n/a
	Manganese	mg/l	n/a	n/a	n/a	n/a	0.182	n/a	n/a	n/a	n/a	n/a	0.206	n/a
Filtered Water	Turbidity	NTU	0.91		0.22		0.217	0.333	0.755	0.263	0.517		0.25	
	Iron	mg/l	0.03	n/a	0.02	n/a	0.07	n/a	0.04	n/a	0.11	n/a	0.03	n/a
	Manganese	mg/l	0.106	n/a	0.113	n/a	0.116	n/a	0.168	n/a	0.277	n/a	0.223	n/a
Treated Water	pH		7.2		7.04		7.29	7.33	7.57	7.38	7.32		6.89	
	Turbidity	NTU	0.32		0.28		0.298	0.397	0.45	0.244	0.187		0.358	
	Colour	PtCo	0.01		0.01		0.01	0.00	0.00	0.01	0.00		0.05	
	Aluminium	µg/l	-		-		-	-	-	-	-		-	
	Iron	mg/l	0.00	n/a	0.01	n/a	0.05	n/a	0.01	n/a	0.04	n/a	0.01	n/a
	Manganese	mg/l	0.068	n/a	0.024	n/a	0.089	n/a	0.088	n/a	0.054	n/a	0.026	n/a
	TFCR	mg/l	2.66		1.42		1.41	0.93	0.97	0.99	0.141		0.59	

Date:19/09/2004			Time											
	Parameter	Unit	12:30 AM	2:30 AM	4:30 AM	6:30 AM	8:30 AM	10:30 AM	12:30 PM	2:30 PM	4:30 PM	6:30 PM	8:30 PM	10:30 PM
Raw Water	Inflow	m3/hr	2266		2286		2510	2485	2462	2630	2692		2268	
	pH		6.66		6.69		6.76	6.73	6.74	6.77	6.77		6.81	
	Turbidity	NTU	1.85		1.86		0.76	2.13	2.16	2.52	2.12		1.88	
	Iron	mg/l	5.87	n/a	5.72	n/a	6.56	n/a	5.16	n/a	7.32	n/a	6.26	n/a
	Manganese	mg/l	0.24	n/a	0.221	n/a	0.25	n/a	0.254	n/a	0.267	n/a	0.257	n/a
Mixing Water	pH		6.91		6.98		6.93	6.98	7.44		7.47		7.48	
Clarified Water	Turbidity	NTU	1.103		0.994		1.294	1.213	1.215	1.086	0.99		0.93	
	Iron	mg/l	n/a	n/a	n/a	n/a	0.87	n/a	n/a	n/a	n/a	n/a	1.92	n/a
	Manganese	mg/l	n/a	n/a	n/a	n/a	0.19	n/a	n/a	n/a	n/a	n/a	0.166	n/a
Filtered Water	Turbidity	NTU	0.116		0.116		0.421	0.162	0.161	0.127	0.155		0.12	
	Iron	mg/l	0.03	n/a	0.03	n/a	0.04	n/a	0.02	n/a	0.03	n/a	0.02	n/a
	Manganese	mg/l	0.18	n/a	0.184	n/a	0.173	n/a	0.141	n/a	0.179	n/a	0.154	n/a
Treated Water	pH		7.37		7.49		7.5	7.27	7.28	7.42	7.16		7.38	
	Turbidity	NTU	0.462		0.436		0.482	0.294	0.273	0.313	0.45		0.5	
	Colour	PtCo	0.03		0.08		0.06	0.09	0.09	0.11	0.12		0.20	
	Aluminium	μg/l	-		-		-	-	-	-	-		-	
	Iron	mg/l	0.01	n/a	0.01	n/a	0.01	n/a	0.01	n/a	0.06	n/a	0.02	n/a
	Manganese	mg/l	0.02	n/a	0.031	n/a	0.053	n/a	0.088	n/a	0.005	n/a	0.079	n/a
	TFCR	mg/l	1.54		2.00		2.25	1.32	1.26	1.15	0.64		1.78	

Date:20/09/2004			Time											
	Parameter	Unit	12:30 AM	2:30 AM	4:30 AM	6:30 AM	8:30 AM	10:30 AM	12:30 PM	2:30 PM	4:30 PM	6:30 PM	8:30 PM	10:30 PM
Raw Water	Inflow	m3/hr	2352		2481		2295		2278		2454		2476	
	pH		6.79		6.79		6.83		6.76		6.74		6.76	
	Turbidity	NTU	2.81		8.81		11.21		9.55		8.62		12.6	
	Iron	mg/l	6.03	n/a	5.89	n/a	7.74	n/a	6.94	n/a	7.59	n/a	5.07	n/a
	Manganese	mg/l	0.27	n/a	0.281	n/a	0.265	n/a	0.238	n/a	0.319	n/a	0.26	n/a
Mixing Water	pH		7.21		7.25		7.23		7.19		7.28		7.28	
Clarified Water	Turbidity	NTU	0.821	0.641	0.646		0.638		0.662		1.046		0.792	
	Iron	mg/l	0.3	n/a	n/a	n/a	0.11	n/a	n/a	n/a	n/a	n/a	0.15	n/a
	Manganese	mg/l	0.203	n/a	n/a	n/a	0.148	n/a	n/a	n/a	n/a	n/a	0.175	n/a
Filtered Water	Turbidity	NTU	0.091	0.078	0.78		0.071		0.075		0.08		0.077	
	Iron	mg/l	0.01	n/a	0.01	n/a	0.01	n/a	0.03	n/a	0.00	n/a	0.00	n/a
	Manganese	mg/l	0.103	n/a	0.157	n/a	0.127	n/a	0.119	n/a	0.132	n/a	0.12	n/a
Treated Water	pH		7.13	7.11	7.15		7.02		7.24		7.41		7.38	
	Turbidity	NTU	0.516	0.442	0.442		0.598		0.44		0.42		0.36	
	Colour	PtCo	0.15	0.01	0.01		0.12		0.03		0.00		0.12	
	Aluminium	µg/l	-	-	-		-		-82.4		-81.5		-67.7	
	Iron	mg/l	0.00	n/a	0.00	n/a	0.00	n/a	0.01	n/a	0.00	n/a	0.00	n/a
	Manganese	mg/l	0.088	n/a	0.095	n/a	0.053	n/a	0.04	n/a	0.091	n/a	0.084	n/a
	TFCR	mg/l	1.87	1.11	1.15		1.37		1.27		1.41		1.05	

Date:21/09/2004

			Time											
	Parameter	Unit	12:30 AM	2:30 AM	4:30 AM	6:30 AM	8:30 AM	10:30 AM	12:30 PM	2:30 PM	4:30 PM	6:30 PM	8:30 PM	10:30 PM
Raw Water	Inflow	m3/hr	2457		2457		2432		2216					
	pH		6.79		6.79		6.84		6.71					
	Turbidity	NTU	12.13		4.47		5.19		11.85					
	Iron	mg/l	6.04	n/a	6.94	n/a	4.92	n/a	6.79	n/a		n/a		n/a
	Manganese	mg/l	0.311	n/a	0.238	n/a	0.263	n/a	0.276	n/a		n/a		n/a
Mixing Water	pH		7.76		6.88		6.93		7.07					
Clarified Water	Turbidity	NTU	0.945		1.079		1.36		77.91					
	Iron	mg/l	0.11	n/a	n/a	n/a	0.98	n/a	n/a	n/a	n/a	n/a		n/a
	Manganese	mg/l	0.109	n/a	n/a	n/a	0.193	n/a	n/a	n/a	n/a	n/a		n/a
Filtered Water	Turbidity	NTU	0.072		0.068		0.115		0.077					
	Iron	mg/l	0.01	n/a	0.02	n/a	0.06	n/a		n/a		n/a		n/a
	Manganese	mg/l	0.14	n/a	0.146	n/a	0.247	n/a		n/a		n/a		n/a
Treated Water	pH		7.21		7.81		7.42		7.42					
	Turbidity	NTU	0.332		0.438		0.479		0.502					
	Colour	PtCo	0.11		0.01		0.01		0.35					
	Aluminium	µg/l	-65.7		176		64.2		100.8					
	Iron	mg/l	0.00	n/a	0.01	n/a	0.06	n/a	0.05	n/a		n/a		n/a
	Manganese	mg/l	0.075	n/a	0.076	n/a	0.085	n/a	0.118	n/a		n/a		n/a
	TFCR	mg/l	1.41		1.5		1.42		1.33					

Date:23/09/2004			Time											
	Parameter	Unit	12:30 AM	2:30 AM	4:30 AM	6:30 AM	8:30 AM	10:30 AM	12:30 PM	2:30 PM	4:30 PM	6:30 PM	8:30 PM	10:30 PM
Raw Water	Inflow	m3/hr	2401		2407		2410		2451		2419		2420	
	pH		6.86		6.86		6.83		6.92		6.85		6.86	
	Turbidity	NTU	5.72		8.03		3.17		5.28		4.94		7.93	
	Iron	mg/l	6.98	n/a	6.54	n/a	6.58	n/a	7.14	n/a	7.89	n/a		n/a
	Manganese	mg/l	0.235	n/a	0.249	n/a	0.207	n/a	0.242	n/a	0.233	n/a	0.251	n/a
Mixing Water	pH		7.39		7.28		7.25		7.33		7.09		6.66	
Clarified Water	Turbidity	NTU	0.3		7.61		4.36		2.853		1.761		1.63	
	Iron	mg/l	n/a	n/a	n/a	n/a	0.57	n/a	n/a	n/a	n/a	n/a		n/a
	Manganese	mg/l	0.192	n/a	n/a	n/a	0.159	n/a	n/a	n/a	n/a	n/a		n/a
Filtered Water	Turbidity	NTU	0.51		1.21		0.42		0.924		0.305		0.25	
	Iron	mg/l	1.13	n/a	0.53	n/a	0.4	n/a	0.2	n/a	-	n/a		n/a
	Manganese	mg/l	0.042	n/a	0.12	n/a	0.095	n/a	0.166	n/a	0.108	n/a	0.004	n/a
Treated Water	pH		7.2		7.26		7.24		7.38		7.46			
	Turbidity	NTU	0.25		0.37		0.5		0.362		0.701		0.68	
	Colour	PtCo	0.43		0.47		0.36		0.49		0.3		0.30	
	Aluminium	µg/l	58.9		0		86.5		59.8		96.9		47.3	
	Iron	mg/l	0.09	n/a	0.04	n/a	0.03	n/a	0.08	n/a	0.06	n/a		n/a
	Manganese	mg/l	0.069	n/a	0.052	n/a	0.035	n/a	0.064	n/a	0.048	n/a	0.008	n/a
	TFCR	mg/l	1.51		2.2		1.02		1.11		1.04		1.22	

)ate:24/09/2004

			Time											
	Parameter	Unit	12:30 AM	2:30 AM	4:30 AM	6:30 AM	8:30 AM	10:30 AM	12:30 PM	2:30 PM	4:30 PM	6:30 PM	8:30 PM	10:30 PM
Raw Water	Inflow	m3/hr	2432				2510		2434		2413			
	pH		6.9		6.83		6.87		6.83		6.85		6.84	
	Turbidity	NTU	5.69		2.94		3.11		3.05		2.53		4.28	
	Iron	mg/l	8.58	n/a	8.95	n/a	7.54	n/a	5.61	n/a	7.14	n/a	6.3	n/a
	Manganese	mg/l	0.261	n/a	0.264	n/a	0.262	n/a	0.256	n/a		n/a	-	n/a
Mixing Water	pH		6.56		6.32		6.48		6.65		6.69		7.41	
Clarified Water	Turbidity	NTU	1.582		1.389		2.062		1.654		1.498		2.029	
	Iron	mg/l	n/a	n/a	n/a	n/a	0.45	n/a	n/a	n/a	n/a	n/a	2.93	n/a
	Manganese	mg/l	n/a	n/a	n/a	n/a	0.252	n/a	n/a	n/a	n/a	n/a	-	n/a
Filtered Water	Turbidity	NTU	0.186		0.133		0.21		0.165		0.123		0.163	
	Iron	mg/l	0.05	n/a	0.05	n/a	0.32	n/a	0.03	n/a	0.14	n/a	0.48	n/a
	Manganese	mg/l	0.226	n/a	0.231	n/a	0.244	n/a	0.142	n/a		n/a	-	n/a
Treated Water	pH		7.49		7.41		7.29		7.26		7.74		6	
	Turbidity	NTU	0.738		0.605		0.554		0.468		0.418		0.323	
	Colour	PtCo	0.32		0.28		0.4		0.64		0.75		0.32	
	Aluminium	µg/l	41.8		31.7		28.4		25.9		26.3		20.1	
	Iron	mg/l	0.05	n/a	0.1	n/a	0.01	n/a	0.02	n/a	0.12	n/a	0.25	n/a
	Manganese	mg/l	0.096	n/a	0.129	n/a	0.146	n/a	0.086	n/a		n/a	-	n/a
	TFCR	mg/l	0.92		1.34		1.15		0.75		0.55		0.8	

Date:25/09/2004

	Parameter	Unit	Time											
			12:30 AM	2:30 AM	4:30 AM	6:30 AM	8:30 AM	10:30 AM	12:30 PM	2:30 PM	4:30 PM	6:30 PM	8:30 PM	10:30 PM
Raw Water	Inflow	m3/hr	2708		2520					2234	2517		2523	
	pH		6.89		6.87		6.82			6.75	6.84		6.88	
	Turbidity	NTU	5.67		4.84		7.91			2.38	2.72		7.63	
	Iron	mg/l	6.23	n/a	6.01	n/a	6.52	n/a		n/a	7.56	n/a	8.67	n/a
	Manganese	mg/l	0.249	n/a	0.236	n/a		n/a		n/a	0.274	n/a	0.204	n/a
Mixing Water	pH		7.2		7.28		7.72				7.14		7.00	
Clarified Water	Turbidity	NTU	3.14		1.76					1.2	1.274		1.931	
	Iron	mg/l	n/a	n/a	n/a	n/a	0.32	n/a	n/a	n/a	n/a	n/a	0.74	n/a
	Manganese	mg/l	n/a	n/a	n/a	n/a		n/a	n/a	n/a	n/a	n/a	0.252	n/a
Filtered Water	Turbidity	NTU	0.201		0.18		0.39			0.101	0.168		0.119	
	Iron	mg/l	0.52	n/a	1.44	n/a	0.03	n/a		n/a	0.06	n/a	0.02	n/a
	Manganese	mg/l	0.199	n/a	0.157	n/a		n/a		n/a	0.14	n/a	0.144	n/a
Treated Water	pH		7.07		7.16		6.36			6.54	7.19		7.24	
	Turbidity	NTU	0.304		0.3		0.33			0.35	0.358		0.369	
	Colour	PtCo	0.35		0.18		0.11			0.00	0.00		0.00	
	Aluminium	µg/l	19.5		13.9		14.5			19.6	19.6		24.4	
	Iron	mg/l	0.11	n/a	0.06	n/a	0.00	n/a		n/a	0.05	n/a	0.01	n/a
	Manganese	mg/l	0.066	n/a	0.053	n/a	0.105	n/a		n/a	0.066	n/a	0.092	n/a
	TFCR	mg/l	0.57		0.95		1.00			0.98	1.26		1.15	

Date:26/09/2004			Time											
	Parameter	Unit	12:30 AM	2:30 AM	4:30 AM	6:30 AM	8:30 AM	10:30 AM	12:30 PM	2:30 PM	4:30 PM	6:30 PM	8:30 PM	10:30 PM
Raw Water	Inflow	m3/hr	2321		2331		2514		2446	2417	2463		2445	
	pH		6.83		6.89		6.93		6.03	6.04	6.05		6.07	
	Turbidity	NTU	3.17		2.88		4.15		15.14	8.09	5.48		16.77	
	Iron	mg/l	8.5	n/a	7.99	n/a	6.36	n/a	7.48	n/a	7.23	n/a	-	n/a
	Manganese	mg/l	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a
Mixing Water	pH		7.44		7.61		7.28		7.63	7.62	7.6		8.43	
Clarified Water	Turbidity	NTU	1.467		1.016		1.234		1.081	1.093	1.12		2.971	
	Iron	mg/l	n/a	n/a	n/a	n/a	0.27	n/a	n/a	n/a	n/a	n/a	-	n/a
	Manganese	mg/l	n/a	n/a	n/a	n/a	-	n/a	n/a	n/a	n/a	n/a	-	n/a
Filtered Water	Turbidity	NTU	0.074		0.077		0.083		0.071	0.082	0.12		0.065	
	Iron	mg/l	0.02	n/a	0.03	n/a	1.02	n/a	0.86	n/a	-	n/a	-	n/a
	Manganese	mg/l	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a
Treated Water	pH		7.09		7.07		7.08		7.26	7.27	7.28			
	Turbidity	NTU	1.376		0.378		0.433		0.42	0.436	0.4		0.47	
	Colour	PtCo	0.00		0.00		0		0.00	0.00	0.06		0.06	
	Aluminium	μg/l	21.8		21.9		32.7		33.6	37.3	47.5		49.9	
	Iron	mg/l	0.00	n/a	0.1	n/a	0.03	n/a	0.02	n/a	-	n/a	-	n/a
	Manganese	mg/l	0.091	n/a	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a
	TFCR	mg/l	0.91		1.57		1.19		1.57	1.57	1.57		1.5	

Date:27/09/2004			Time											
	Parameter	Unit	12:30 AM	2:30 AM	4:30 AM	6:30 AM	8:30 AM	10:30 AM	12:30 PM	2:30 PM	4:30 PM	6:30 PM	8:30 PM	10:30 PM
Raw Water	Inflow	m3/hr					2407		2470		2454		2454	
	pH		6.08		6.08		6.1		6.03		6		5.99	
	Turbidity	NTU	17.00		10.67		11.59		9.53		9.5		9.54	
	Iron	mg/l	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a
	Manganese	mg/l	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a
Mixing Water	pH		7.92				7.64		7.4		8.09		6.40	
Clarified Water	Turbidity	NTU	1.082		0.933		0.88		0.865		1.112		1.478	
	Iron	mg/l	n/a	n/a	n/a	n/a	-	n/a	n/a	n/a	n/a	n/a	-	n/a
	Manganese	mg/l	n/a	n/a	n/a	n/a	-	n/a	n/a	n/a	n/a	n/a	-	n/a
Filtered Water	Turbidity	NTU	0.228		0.093		0.08		0.131		0.155		0.173	
	Iron	mg/l	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a
	Manganese	mg/l	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a
Treated Water	pH		7.17		7.19		7.26		7.15		7.33		7.34	
	Turbidity	NTU	0.417		0.328		0.33		0.875		0.473		0.855	
	Colour	PtCo	0.00		0.02		0.01		0.11		0.04		0.23	
	Aluminium	µg/l	57.4		85.4		89.9		193.9		131.1		106	
	Iron	mg/l	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a
	Manganese	mg/l	-	n/a	-	n/a	-	n/a	-	n/a	0.00	n/a	-	n/a
	TFCR	mg/l	1.7		1.63		1.54		1.62		1.09		1.42	

Date:28/09/2004			Time											
	Parameter	Unit	12:30 AM	2:30 AM	4:30 AM	6:30 AM	8:30 AM	10:30 AM	12:30 PM	2:30 PM	4:30 PM	6:30 PM	8:30 PM	10:30 PM
Raw Water	Inflow	m3/hr	2230		2230		2443				2461		2420	
	pH		5.97		5.97		5.97		5.04		6.7		6.02	
	Turbidity	NTU	9.94		9.96		10.13				8.8		9.02	
	Iron	mg/l	-	n/a	-	n/a	-	n/a	9.12	n/a	9.48	n/a	9.24	n/a
	Manganese	mg/l	-	n/a	-	n/a	-	n/a		n/a	-	n/a	-	n/a
Mixing Water	pH		8.23		7.98		7.82		7.26		6.97			
Clarified Water	Turbidity	NTU	1.32		0.85		0.51				1.866		1.56	
	Iron	mg/l	n/a	n/a	n/a	n/a	-	n/a	n/a	n/a	n/a	n/a	0.99	n/a
	Manganese	mg/l	n/a	n/a	n/a	n/a	-	n/a	n/a	n/a	n/a	n/a	-	n/a
Filtered Water	Turbidity	NTU	0.12		0.07		0.08		0.086		0.098		0.094	
	Iron	mg/l	-	n/a	-	n/a	-	n/a	0.01	n/a	0.04	n/a	0.03	n/a
	Manganese	mg/l	-	n/a	-	n/a	-	n/a		n/a	-	n/a	-	n/a
Treated Water	pH		6.93		7.56		7.65		6.97		7.46			
	Turbidity	NTU	0.52		0.21		0.28		0.385		0.438		0.374	
	Colour	PtCo	0.13		0.2		0.34		0.20		0.22		0.01	
	Aluminium	µg/l	65.7		90.3		87.8		93.5		56.5		44.9	
	Iron	mg/l	-	n/a	-	n/a	-	n/a	0.07	n/a	0.05	n/a	0.03	n/a
	Manganese	mg/l	-	n/a	-	n/a	-	n/a		n/a	-	n/a	-	n/a
	TFCR	mg/l	0.98		1.3		1.25		0.79		0.88		0.81	

Date:29/09/2004

			Time											
	Parameter	Unit	12:30 AM	2:30 AM	4:30 AM	6:30 AM	8:30 AM	10:30 AM	12:30 PM	2:30 PM	4:30 PM	6:30 PM	8:30 PM	10:30 PM
Raw Water	Inflow	m3/hr	2431		2426		2686		2476					
	pH		6.03		6.02		6.15		6.01		5.94		5.98	
	Turbidity	NTU	8.17		6.9		4.9		6		5.65		5.64	
	Iron	mg/l	8.88	n/a	8.63	n/a	9	n/a	8.7	n/a	6.72	n/a	7.14	n/a
	Manganese	mg/l	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a
Mixing Water	pH		6.78		6.8		6.78		7.16		7.04		6.90	
Clarified Water	Turbidity	NTU	1.715		1.57		1.63		1.683		1.883		1.443	
	Iron	mg/l	n/a	n/a	n/a	n/a	1.26	n/a	n/a	n/a	0.42	n/a	0.68	n/a
	Manganese	mg/l	n/a	n/a	n/a	n/a		n/a	n/a	n/a	n/a	n/a	-	n/a
Filtered Water	Turbidity	NTU	0.106		0.118		0.106		0.106		0.084		0.162	
	Iron	mg/l	0.29	n/a	0.24	n/a	0.04	n/a	0.07	n/a	0.32	n/a	0.06	n/a
	Manganese	mg/l	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a
Treated Water	pH		7.42		7.48		7.41		7.56		6.93		6.55	
	Turbidity	NTU	0.35		0.311		0.216		0.276		0.334		0.317	
	Colour	PtCo	0.17		0.2		0.06		0.26		0.37		0.00	
	Aluminium	µg/l	28.1		22.2		16.7		18.7		18.6		23.2	
	Iron	mg/l	0.08	n/a	0.05	n/a	0.03	n/a	0.04	n/a	-0.02	n/a	0.07	n/a
	Manganese	mg/l	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a
	TFCR	mg/l	0.46		0.3		0.25		1.3		1.24		1.2	

Date:30/09/2004			Time											
	Parameter	Unit	12:30 AM	2:30 AM	4:30 AM	6:30 AM	8:30 AM	10:30 AM	12:30 PM	2:30 PM	4:30 PM	6:30 PM	8:30 PM	10:30 PM
Raw Water	Inflow	m3/hr	2484		2407		2229		2231		2235		2237	
	pH		6.03		6.01		5.99		5.97		5.96		6.01	
	Turbidity	NTU	5.20		5.31		4.73		4.25		4.06		3.08	
	Iron	mg/l	7.68	n/a	8.04	n/a	6.75	n/a	6.84	n/a	6.27	n/a	6.67	n/a
	Manganese	mg/l	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a
Mixing Water	pH		6.96		6.87		7.2		7.29		7.39		7.55	
Clarified Water	Turbidity	NTU	1.5		1.51		1.53		1.124		1.019		1.63	
	Iron	mg/l	n/a	n/a	n/a	n/a	1.35	n/a	n/a	n/a	n/a	n/a	0.63	n/a
	Manganese	mg/l	n/a	n/a	n/a	n/a	-	n/a	n/a	n/a	n/a	n/a	-	n/a
Filtered Water	Turbidity	NTU	0.14		0.2		0.157		0.111		0.091		0.071	
	Iron	mg/l	0.12	n/a	0.19	n/a	0.03	n/a	0.06	n/a	0.01	n/a	0.09	n/a
	Manganese	mg/l	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a
Treated Water	pH		6.73		6.68		7.3		7.29		6.83		6.95	
	Turbidity	NTU	0.32		0.35		0.366		0.33		0.476		0.34	
	Colour	PtCo	0.00		0.02		0.03		0.21		0.28		0.00	
	Aluminium	µg/l	28.7		17.5		20.4		17.6		26.3		29.6	
	Iron	mg/l	0.03	n/a	0.02	n/a	0.09	n/a	0.08	n/a	0.05	n/a	0.02	n/a
	Manganese	mg/l	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a	-	n/a
	TFCR	mg/l	1.3		1.32		1.40		1.8		1.49		1.65	

Appendix B: Complete set of trial-error tables (UTP)

Aeration	Iron (mg/l)				Manganese(mg/l)			
	1	2	3	Average	1	2	3	Average
First Batch (Zero hour)	0.113	0.1	0.225	0.146	0.003	0.009	0.006	0.006
2nd Batch (1 hour)	0.159	0.121	0.106	0.128	-0.006	-0.006	-0.002	-0.00467
3rd Batch (2 hours)	0.078	0.055	0.061	0.064	-0.006	0.007	0.005	0.002
4th Batch (3 hours)	0.16	0.133	0.101	0.131	0.021	0.009	0.021	0.017
5th Batch (4 hours)	0.229	0.17	0.096	0.165	0.03	0.035	0.025	0.03

Table of Fe and Mn Concentrations

Test: Addition of Alum %
(10 mg/l – 100mg/l)

		1	2	3	4	5	6	Raw Water
	conc ml	10 mg/l (0.1ml)	20 mg/l (0.2ml)	30 mg/l (0.3ml)	50 mg/l (0.5ml)	75 mg/l (0.75ml)	100 mg/l (1ml)	0
pH		5.97	5.95	5.91	5.88	5.45	4.34	7.74
Fe (mg/l)	1	0.025	0.006	0.043	1.628	0.105	0.105	0.043
	2	0.065	0.098	0.012	0.095	0.006	0.099	0.042
	3	0.04	0.02	0.006	0.019	0.041	0.068	0.003
	Average	0.043333333	0.041333333	0.020333333	0.580666667	0.050666667	0.090666667	0.0293333
Mn (mg/l)	1	0.002	0.006	0.012	0.03	0.005	0.01	0.012
	2	0.006	0.006	0.003	0.02	0.025	0.02	0.021
	3	0.006	0.006	0.003	0	0.02	0.02	0.018
	Average	0.004666667	0.006	0.006	0.016666667	0.016666667	0.016666667	0.017
Floc		fine, on the top	fine, on the top	blurry, less floc	blurry, less floc	very fine, less floc	very fine, too blurry	

Test: Addition of Alum %
(8mg/l – 80 mg/l)

		1	2	3	4	5	6	Raw Water
	conc ml	8 mg/l (0.1ml)	16 mg/l (0.2ml)	24 mg/l (0.3ml)	36 mg/l (0.5ml)	52 mg/l (0.75ml)	80 mg/l (1ml)	0
pH		3.89	3.81	3.78	3.75	3.74	3.66	7.74
Fe (mg/l)	1	0.068	0.032	0.057	0.039	0.109	0.046	0.043
	2	0.027	0.037	0.098	0.043	0.061	0.126	0.042
	3	0.02	0.074	0.004	0.043	0.103	0.13	0.003
	Average	0.038333333	0.047666667	0.053	0.041666667	0.091	0.100666667	0.0293333
Mn (mg/l)	1	0.001	0.006	0.006	0.005	0.007	0.015	0.012
	2	0.001	0.006	0.011	0.011	0.01	0.015	0.021
	3	0.006	0.006	0.005	0.007	0.008	0.02	0.018
	Average	0.002666667	0.006	0.007333333	0.007666667	0.008333333	0.016666667	0.017
Floc		clean,less floc	blurry, fine floc	blurry, fine floc	blurry, less floc	very fine, yellowish	bottom:big floc, fine	

Appendix C: Complete set of 2^{nd} test results; tables (UTP)

Aeration	Iron (mg/l)				Manganese(mg/l)			
	1	2	3	Average	1	2	3	Average
First Batch (Zero hour)	0.254	0.21	0.355	0.273	-0.006	0.307	-0.006	0.098
2nd Batch (1 hour)	0.254	0.178	0.259	0.23	0.592	0.633	0.163	0.462
3rd Batch (2 hours)	0.281	0.11	0.156	0.182	0.164	0.176	0.179	0.173
4th Batch (3 hours)	0.231	0.15	0.188	0.189	0.181	0.179	0.175	0.178

Table of Fe and Mn Concentrations

Test: Addition of Alum %
(1mg/l – 10 mg/l)

		1	2	3	4	5	6	Raw Water
	conc ml	1.0 mg/l (0.01ml)	2.0 mg/l (0.02ml)	3.0 mg/l (0.03ml)	5.0 mg/l (0.05ml)	7.5 mg/l (0.075ml)	10.0 mg/l (0.1ml)	0
pH		7.57	7.64	7.58	7.67	7.71	7.72	7.91
Fe (mg/l)	1	0.189	0.2	0.142	0.108	0.068	0.037	0.043
	2	0.117	0.082	0.027	0.063	0.041	0.042	0.07
	3	0.121	0.032	0.126	0.114	0.042	0.048	0.043
	Average	0.142333333	0.104666667	0.098333333	0.095	0.050333333	0.042333333	0.052
Mn (mg/l)	1	0.185	0.186	0.167	0.179	0.151	0.133	0.132
	2	0.183	0.196	0.163	0.168	0.148	0.127	0.137
	3	0.18	0.187	0.179	0.17	0.141	0.129	0.136
	Average	0.182666667	0.189666667	0.169666667	0.172333333	0.146666667	0.129666667	0.135
Floc		fine, on the top	fine, on the top	blurry, less floc	blurry, less floc	very fine, less floc	very fine, too blurry	

Test: Addition of Alum %
(0.8 mg/l – 8 mg/l)

		1	2	3	4	5	6	Raw Water
	conc ml	0.8 mg/l (0.01ml)	1.6 mg/l (0.02ml)	2.4 mg/l (0.03ml)	3.6 mg/l (0.05ml)	5.2 mg/l (0.075ml)	8.0 mg/l (0.1ml)	0
pH		7	7.06	7.14	7.18	7.24	7.26	7.91
Fe (mg/l)	1	0.106	0.097	0.033	0.003	0.001	0.003	0.043
	2	0.055	0.002	0.047	0.009	0.006	0.012	0.07
	3	0.132	0.017	0.043	0.007	0.01	0.002	0.043
	Average	0.097666667	0.038666667	0.041	0.006333333	0.005666667	0.005666667	0.052
Mn (mg/l)	1	0.197	0.176	0.173	0.173	0.142	0.121	0.132
	2	0.197	0.179	0.17	0.173	0.138	0.128	0.137
	3	0.197	0.179	0.166	0.173	0.144	0.019	0.136
	Average	0.197	0.178	0.169666667	0.173	0.141333333	0.089333333	0.135
Floc		clean, much floc	blurry, fine floc	blurry, much floc	clean, fine floc	clean, fine floc	clean, less floc	

Appendix D: Complete set of tables of experiments conducted at the Chicha Water plant

Test 1 : Addition of Alum

		Raw Water	1	2	3	4	5
	conc ml	0	5 mg/l (0.5ml)	10 mg/l (1ml)	15 mg/l (1.5 ml)	20 mg/l (2.0 ml)	25 mg/l (2.5 ml)
pH (settled water)		6.18	6.08	5.69	4.96	4.73	4.53
pH (filtered water)		6.42	6.48	6.15	5.38	4.72	4.54
Fe (mg/l)		4.52	5.22	5.52	5.74	5.68	6.34
Mn (mg/l)		0.259	0.236	0.236	0.235	0.101	0.09

Note: Raw Water pH = 6.1

Raw Water Fe(mg/l) = 5.52

Raw Water Mn (mg/l) = 0.238

Test 2 Addition of Alum + Lime

		Raw Water	1	2	3	4	5
conc ml	Alum	0	5 mg/l (0.5ml)	10 mg/l (1ml)	15 mg/l (1.5 ml)	20 mg/l (2.0 ml)	25 mg/l (2.5 ml)
	Lime	0	20 mg/l (2.0 ml)	30 mg/l (3.0 ml)	40 mg/l (4.0 ml)	50 mg/l (5.0 ml)	60 mg/l (6.0 ml)
pH (settled water)		6.36	6.43	6.25	6.03	5.6	5.52
pH (filtered water)		6.55	6.56	6.52	6.38	6.27	5.87
Fe (mg/l)		4.76	4.08	3.7	3.86	4.1	4.54
Mn (mg/l)		0.214	0.197	0.198	0.202	0.22	0.192

Note: Raw Water Fe(mg/l) = 5.64

Raw Water Mn (mg/l) = 0.231

Appendix E: Chicha Water experiment results conducted by Hj Hasani

Test: Chicha Lab Results

Date : 19/03/05

		1	2	3	4	5	6
conc ml	Hypo	8 mg/l (0.8ml)	8 mg/l (0.8ml)	8 mg/l (0.8ml)	8 mg/l (0.8ml)	8 mg/l (0.8ml)	8 mg/l (0.8ml)
	Lime	20 mg/l (2.0 ml)	30 mg/l (3.0 ml)	35 mg/l (3.5 ml)	40mg/l (4.0 ml)	45 mg/l (4.5 ml)	50 mg/l (5.0 ml)
Settled Water							
pH		6.49	6.36	6.31	6.35	6.41	6.48
Fe (mg/l)		1.38	1.35	1.36	0.99	0.48	0.7
Mn (mg/l)		0.067	0.066	0.062	0.07	0.068	0.05
Cl		0.46	0.66	0.58	0.51	0.56	0.68
Filtered Water							
pH		7.19	7.2	7.17	7.37	7.17	7.17
Fe (mg/l)		0.15	0.23	0.09	0.03	0.012	0.011
Mn (mg/l)		0.87	0.077	0.064	0.066	0.089	0.087

Note: Raw Water pH = 6.1

Raw Water Fe(mg/l) = 5.52

Raw Water Mn (mg/l) = 0.238

Appendix F: Complete set of tables of experiments conducted in UTP

1st test

Aeration	Iron (mg/l)				Manganese(mg/l)			
	1	2	3	Average	1	2	3	Average
Raw Water	1.165	1.144	1.09	1.13	0.189	0.188	0.182	0.19
1st Batch (1 hour)	1.076	1.06	1.137	1.09	0.19	0.186	0.183	0.19
2nd Batch (2 hours)	0.925	0.914	0.994	0.94	0.198	0.187	0.185	0.19
3rd Batch (3 hours)	1.06	1.101	1.117	1.09	0.179	0.19	0.184	0.18

Jar Test 1 : Addition of Alum (UTP)

		Raw Water	1	2	3	4	5
	conc ml	0	5 mg/l (0.5ml)	10 mg/l (1ml)	15 mg/l (1.5 ml)	20 mg/l (2.0 ml)	25 mg/l (2.5 ml)
pH		7.36	6.48	5.85	4.95	4.62	4.51
Fe (mg/l)		0.06	0.03	0.02	0.02	0.03	0.03
Mn (mg/l)		0.374	0.213	0.212	0.139	0.054	0.035

pH Raw Water = 7.21

Jar Test 1 : Addition of Hypo (UTP)

Hypo Conc (mg/l)	Fe (mg/l)	Mn (mg/l)
0	9.3	23.2
45.6	8.08	19.2
91.2	9.6	16
136.8	9.03	15.6
182.4	8.31	14.7
228	7.95	13.2